

### APPENDIX 3

#### BLEACHING CHEMICAL SEQUENCES

A variety of bleaching sequences were used in producing high brightness chemically pulped paper grades. typically these involved reaction stages followed by extraction and washing. The following table (as presented in Pulp and Paper, November 1991) lists the chemicals used in pulp bleaching and the symbols used to describe them. For example, the sequence CEDED involved a chlorine bleaching stage followed by caustic extraction, further bleaching with chlorine dioxide, a second extraction, and finally a second chlorine dioxide polishing stage. An OZEP line would use oxygen delignification, ozone bleaching, caustic extraction, and finally hydrogen peroxide bleaching. OZEP would be a totally chlorine free process.

C	Chlorination
C <sub>D</sub>	Chlorination with chlorine dioxide substitution
E	Caustic Extraction
E <sub>O</sub>	Caustic Extraction with oxygen reinforcement
O	Oxygen Delignification
Z	Ozone Bleaching
ZW	Ozone filtrate wash
P	Peroxide
H	Hypochlorite
Y	Sodium Hydrosulfite

**Table 1**  
**1990 Pulp and Paper Production**  
 (thousand tons)

	Paper Production	Pulp Production
United States	71,519	57,214
Japan	28,086	11,328
Canada	16,466	22,835
China (People's Republic)	13,719	10,270
Germany (West)	11,873	2,339
U.S.S.R.	9,800	9,600
Finland	8,958	8,886
Sweden	8,426	9,914
France	7,049	2,200
Italy	5,601	676
Brazil	4,844	4,453
United Kingdom	4,824	595

Source: Pulp & Paper International: 1992 International Fact & Price Book

Table 2  
Paper Production by Market Segment  
(thousand tons)

	United States	Canada	Japan	Germany (West)	Finland	Sweden	France	Italy	United Kingdom
<b>Paper:</b>									
Newspaper	5,997	9,068	3,479	1,118	1,430	2,273	422	233	696
Printing & Writing	20,097	3,599	7,218	5,008	4,766	1,655	2,773	2,242	1,387
Household/Tissue	5,264	472	1,366	828	167	283	329	261	440
Other	1,842	0	4,064	281	174	124	246	173	128
<b>Paperboard:</b>									
Greaseproof	511	0	0	94	40	22	0	58	15
Linerboard/Fluting	24,460	2,062	8,275	2,082	716	1,777	2,192	1,278	1,303
Sacks	2,596	493	648	62	434	837	197	80	81
Boxboard	6,871	449	2,242	859	972	1,323	330	715	465
Other	4,524	343	792	1,541	265	124	559	541	540
<b>Total</b>	<b>72,162</b>	<b>16,486</b>	<b>28,084</b>	<b>11,873</b>	<b>8,964</b>	<b>8,418</b>	<b>7,048</b>	<b>5,581</b>	<b>5,055</b>

Source: OECD: The Pulp and Paper Industry, 1990

Table 3  
Pulp Production by Market Segment  
(thousand tons)

	United States	Canada	Japan	Germany (West)	Finland	Sweden	France	Italy	United Kingdom
Pulp:									
Mechanical	5,772	10,537	2,047	1,496	3,293	2,953	556	449	995
Semi-Chemical	3,828	465	324	76	434	284	112	88	0
Bleached Kraft	25,002	8,802	6,950	0	4,198	3,551	838	0	0
Unbleached Kraft	20,024	1,360	1,771	0	671	2,097	474	0	0
Sulphate	1,416	1,451	31	661	102	733	221	54	0
Dissolving Pulp	1,173	221	187	106	188	296	0	30	0
Other Pulp	0	0	0	0	0	0	0	96	0
Total	57,215	22,836	11,310	2,339	8,886	9,914	2,203	717	995

Source: OECD: The Pulp and Paper Industry, 1990

# The Pulp and Paper industry

Table 4  
World Export Share of Paper and Paperboard

	1990	1985	1980
Canada	15.2%	22.2%	19.1%
Finland	13.7%	14.0%	13.7%
Sweden	11.8%	12.0%	13.4%
Germany West,	11.61	10.5%	8.9%
United States	7.8%	8.0%	10.6%
France	6.0%	4.7%	5.2%
Netherlands	4.5%	3.5%	3.8%
Austria	4.1%	3.1%	3.1%
United Kingdom	4.3%	3.1%	3.6%
Italy	3.1%	3.0%	1.9%

Source: UN Trade Statistics Yearbook, 1990

Table 5  
World Import Share of Paper and Paperboard

	1990	1985	1980
Canada	2.6%	2.3%	1.6%
Finland	0.4%	0.5%	
Sweden	0.9%	1.0%	1.0%
Germany West	13.6%	10.6%	13.8%
United States	16.3%	24.5%	16.5%
France	9.2%	7.1%	8.3%
Netherlands	4.5%	9.2%	5.3%
Austria	1.0%	1.3%	1.0%
United Kingdom	12.0%	10.6%	12.8%
Italy	5.0%	3.7%	3.4%

Source: UN Trade Statistics Yearbook, 1990

Table 6  
Balance of Trade in Paper and Paperboard  
(million dollars)

	1990	1985	1980
Canada	6.382	4.315	3.619
Finland	6.570	3.021	
Sweden	5.367	2.453	2569
Germany (west)	(1.168)	(1.35)	(1.043)
United States	(4430)	(3898)	(1.258)
France	(1694)	(607)	(641)
Netherlands	(446)	(255)	(316)
Austria	1.360	456	420
United Kingdom	(3.908)	(2.048)	(1.925)
Italy	(1.003)	(188)	(1.108)

Source: UN Trade Statistics Yearbook, 1990

Table 7  
World Export Share of Pulp and Waste Paper

Country	1990	1985	1980
Canada	30.92 %	30.98 %	33.36 %
U.S.	23.62 %	21.93 %	20.81 %
Sweden	11.44 %	13.83 %	14.38 %
Finland	6.00 %	6.81 %	2.16 %
Portugal	3.99 %	3.52 %	1.92 %
Brazil	3.51 %	4.21 %	0.00 %
Norway	2.34 %	1.45 %	2.16 %
Spain	2.09 %	1.42 %	0.86 %
France	2.23 %	2.19 %	0.86 %
Chile	2.14 %	1.45 %	N.A

Source: UN Trade Statistics Yearbook, 1990

Table 8  
World Import Share of Pulp and Waste Paper

Country	1990	1985	1980
Canada	1.56 %	1.83 %	1.32 %
U.S.	16.27 %	17.87 %	17.60 %
Sweden	0.87 %	0.79 %	0.51 %
Finland	0.36 %	0.32 %	0.20 %
Portugal	0.24 %	0.23 %	0.19 %
Brazil	0.20 %	0.05 %	0.38 %
Norway	0.32 %	0.50 %	1.39 %
Spain	2.29 %	2.20 %	1.97 %
France	7.50 %	7.96 %	9.16 %
Chile	0.00 %	0.00 %	N.A

Source: UN Trade Statistics Yearbook, 1990

Table 9  
Balance of Trade in Pulp and Waste Paper  
(million dollars)

Country	1990	1985	1980
Canada	5,000	2,369	3,199
U.S.	1,034	238	313
Sweden	11,795	11,060	11,384
Finland	959	527	195
Portugal	638	268	172
Brazil	563	339	(38)
Norway	341	75	75
Spain	(65)	(750)	(111)
France	(1004)	(512)	(831)
Chile	367	119	N.A

Source: UN Trade Statistics Yearbook, 1990

# The Pulp and Paper Industry

Table 10  
World Export Share of Newsprint

Country	1990	1985	1980
Canada	56.75 %	68.25 %	61.72 %
Sweden	13.14 %	8.88 %	11.72 %
Finland	8.66 %	10.29 %	12.73 %
Norway	5.33 %	4.23 %	4.90 %
U.S.	3.58 %	2.69 %	2.15 %
Germany (West)	3.16 %	1.22 %	0.89 %
Netherlands	1.69 %	.59 %	0.48 %
New Zealand	1.31 %	0.31 %	1.76 %
South Africa	0.39 %	0.59 %	N.A.
U.K.	1.42 %	0.41 %	0.65 %

Source: UN Trade Statistics Yearbook, 1990

Table 11  
World Import Share of Newsprint

Country	1990	1985	1980
Canada	0.00 %	0.00 %	0.00 %
Sweden	0.00 %	0.00 %	0.00 %
Finland	0.00 %	0.00 %	0.00 %
Norway	0.00 %	0.00 %	0.00 %
U.S.	47.07 %	67.42 %	49.18 %
Germany (West)	9.05 %	6.30 %	8.94 %
Netherlands	2.88 %	1.92 %	3.35 %
New Zealand	0.12 %	0.27 %	0.00 %
So. Africa	0.00 %	0.00 %	N.A.
U.K.	10.17 %	9.66 %	11.81 %

Source: UN Trade Statistics Yearbook, 1990

Table 12  
Balance of Trade in Newsprint  
(million dollars)

Country	1990	1985	1980
Canada	5,044	3,959	3,144
Sweden	1,168	515	597
Finland	770	597	649
Norway	473	245	250
U.S.	(4,141)	(3,564)	(2,633)
Germany (West)	(577)	(277)	(453)
Netherlands	(122)	(72)	(162)
New Zealand	105	3	90
South Africa	35	34	N.A.
U.K.	(838)	(509)	(626)

Source: UN Trade Statistics Yearbook, 1990

Table 13  
World Export Share of Printing and Writing Papers

Country	1990	1985	1980
Finland	16.25%	22.79%	18.98%
Germany (West)	15.30%	15.75%	12.89%
Austria	10.27%	7.56%	7.34%
France	10.09%	7.38%	8.97%
Sweden	9.26%	6.47%	6.89%
Italy	5.14%	5.66%	5.33%
Netherlands	5.65%	4.53%	4.69%
Belgium	4.71%	2.42%	4.52%
Canada	4.09%	6.88%	6.17%
Japan	3.05%	5.24%	5.79%

Source: UN Trade Statistics Yearbook, 1990

Table 14  
World Import Share of Printing and Writing Papers

Country	1990	1985	1980
Finland	0.29%	0.16%	0.00%
Germany West	14.68%	12.87%	18.43%
Austria	1.45%	1.23%	0.98%
France	9.58%	8.41%	10.19%
Sweden	0.79%	0.65%	0.58%
Italy	4.05%	3.61%	2.99%
Netherlands	5.28%	5.20%	6.53%
Belgium	5.05%	4.30%	5.78%
Canada	2.89%	3.10%	2.26%
Japan	1.12%	0.99%	0.52%

Source: UN Trade Statistics Yearbook, 1990

Table 15  
Balance of Trade in Printing and Writing Papers  
(million dollars)

Country	1990	1985	1980
Finland	1,736	1,444	1,037
Germany (West)	34	136	(279)
Austria	957	400	349
France	34	(97)	(53)
Sweden	920	369	346
Italy	109	118	131
Netherlands	28	(62)	(92)
Belgium	(48)	(136)	(62)
Canada	124	230	217
Japan	208	268	289

Source: UN Trade Statistics yearbook, 1990

Table 16  
World Export Share of Bleached Nondissolving Pulp

Country	1990	1985	1980
Canada	37.06%	39.55%	44.22%
U.S.	20.45%	17.76%	16.57%
Sweden	12.37%	15.50%	14.56%
Finland	6.94%	7.21%	9.25%
Brazil	5.05%	5.90%	N.A.
Portugal	4.87%	4.51%	2.17%
Spain	2.87%	1.95%	0.94%
Chile	2.35%	1.64%	N.A.
France	1.37%	1.39%	0.72%
Belgium	1.12%	1.01%	1.07%

Source: UN Trade Statistics Yearbook, 1990

Table 17  
World Import Share of Bleached Nondissolving Pulp

Country	1990	1985	1980
Canada	0.80%	1.13%	0.68%
U.S.	19.50%	22.20%	21.91%
Sweden	.52%	0.25%	0.25%
Finland	0.06%	0.06%	0.00%
Brazil	0.11%	0.03%	N.A.
	0.18%	0.29%	0.20%
Spain	2.12%	1.92%	1.95%
Chile	0.00%	0.00%	N.A.
France	9.57%	9.59%	10.55%
Belgium	2.13%	2.07%	1.65%

Source: UN Trade Statistics Yearbook, 1990

Table 18  
Balance of Trade in Bleached Nondissolving Pulp  
(million dollars)

Country	1990	1985	1980
Canada	4,204	2,025	2,752
U.S.	(70)	(288)	(301)
Sweden	1,371	802	904
Finland	798	377	584
Brazil	573	310	N.A.
Portugal	544	222	125
Spain	68	(3)	(61)
Chile	273	87	N.A.
France	(1,041)	(456)	(603)
Belgium	(137)	(61)	(34)

Source: UN Trade Statistics Yearbook, 1990

Table 19  
Segment Production Levels for  
Georgia Pacific and Champion International

Georgia-Pacific	Capacity ('000 tons)	Champion International	Capacity ('000 tons)
Paper:		Paper:	
Communication	2,240	Uncoated Free Sheet	1,542
		Coated Free Sheet	555
Groundwood Papers	603	Coated Groundwood	733
		Uncoated Groundwood	271
		Newsprint	893
Tissue	573		
Containerboard and Packaging		Containerboard and Packaging:	
Kraft Paper	342	Kraft Paper	99
Linerboard and Medium	2,941	Linerboard	391
		Bleached Board	284
Other Paperboard	629		
Market Pulp	1,866	Market Pulp	986

Source: Company Financial Documents

Table 20  
Forest Resources of Major Pulp Producing Nations

	Total Land Area (thousand sq.km)	Forested Land Area (thousand sq. km.)	Share of Land A r e a Forests
United States	9,373	2,960	32%
Canada	9,976	4,364	44%
Sweden	450	278	62%
Finland	338	232	69%
Germany (West)	357	72	20%
Japan	378	253	67%

Source: World Bank World Development Report 1993

Table 21  
Toxic Releases of the U.S. Pulp and Paper Industry  
1989 Results of Toxic Release inventory

	Share of Pulp and Paper Emissions	Pulp and Paper Lrldusny share of Total Emissions
Methanol	37.8%	29.0%
Toluene	11.5%	11.2%
Hydrochloric Acid	8.6%	5.5%
Sulfuric Acid	7.4%	7.3%
Chloroform	6.4%	75.0%
Acetone	5.7%	7.0%
Ammonium Sulfate	4.2%	1.7%
Chlorine	3.2%	7.1%
Methyl Ethyl Ketone	2.6%	5.3%
Chlorine Dioxide	2.0%	87.7%
Top Ten	89.5%	

Source: 1989 Toxic Release Inventory (U.S. EPA)

Table 22  
Per Capita Paper Consumption

Country	1990 (kg/capita)	1985 (kg/capita)	5 Year Annual Growth
<b>Leaders:</b>			
United States	311.4	282.9	1.93%
Finland	279.2	275.4	0.3%
Germany (West)	231.5	174.1	5.9%
Sweden	230.7	238.5	-0.7%
Japan	228.3	167.7	6.4%
Canada	215.3	199.4	1.5%
Switzerland	214.5	178.7	3.7%
Belgium	210.1	163.4	5.1%
Denmark	205.4	174.1	3.4%
Netherlands	203.2	171.0	3.5%
<b>Others of Interest:</b>			
Australia	164.8	149.2	2.0%
New Zealand	168.9	195.1	-2.8%
Brazil	27.6	26.8	0.6%
China	12.6	9.4	6.0%
U. S. S. R.	32.8	33.4	0.4%

Source: Pulp & Paper International:1992 International Fact & Price Book

Table 23  
Largest Pulp and Paper Companies

Rank	Company	1990 Sales from Pulp and Paper (\$ million)	Headquarters Country
1	International Paper	\$10,610	U.S.
2	Georgia Pacific	\$6,702	U.S.
3	Stone Container	\$6,434	U.S.
4	Kimberly-Clark	\$6,205	U.S.
5	Stora	\$5,728	Sweden
6	James River	\$5,400	U.S.
7	Scott Paper	\$5,356	U.S.
8	Arjo Wiggins Appleton	\$4,638	U.K.
9	Svenska Cellulosa	\$4,291	Sweden
10	Champion International	\$4,103	U.S.
11	Weyerhaeuser	\$3,931	U.S.
12	Ōji Paper	\$3,526	Japan
13	Jufo Paper	\$3,473	Japan
14	MoDo	\$3,076	Sweden
15	Jefferson Smurfit Corp	\$2,919	U.S.

Source: Pulp & Paper International: 1992 International Fact & Price Book

Table 24  
Characteristics of Top 100 Paper Companies

	1981 Number	Average Production (000 tpy)	1991 Number	Average Production (000 tpy)
North America	44	1453	35	2447
Europe	39	712	43	12436
Others	17	800	22	1308
Total	100	1047	100	1678

Source: CEPI/PPI, Clark D., 'The West European Paper Industry in 1993.' Paper and Packaging analyst No. 13, May 1993, The Economist Economic Intelligence Unit

Table 25  
Chemicals Used in Paper Production

Chemical	1990 (thousand tons)	Anticipated Annual Change (1990-2000)
Sodium Hydroxide	2,500	-1%
Chlorine	1,400	-5%
Sodium Chlorate	1,000	8%
Oxygen	800	3%
Sodium Sulfate	300	-1%
Titanium Dioxide	250	3%
Soda Ash	150	6%
Hydrogen Peroxide	80	9%
Ozone	<1	30%

Source: Chemicalweek, May 8, 1991

# GUIDELINES ON DIOXIN

December 20, 1991

## I.. Voluntary Goal of AOX Level in Effluent

All bleached pulp mills are requested to hold the amount of organic chlorine in effluent within AOX 1. 5 kg or less per pulp metric ton by the end of 1993.

## II. Equipment and Operation

Followings are guidelines to the equipment and operation of pulp mills. These are in order to restrain the occurrence of dioxin in bleached sulfate pulp and dissolving pulp mills.

(1) To promote the delignification in cooking process

(2) To diminish lignin in bleaching process by fully washing in washing and screen processes.

• (3) In Bleaching Process

a. to diminish chlorine use by the introduction of oxygen bleaching

b. to get down the chlorine adding rate to K value (index of the amount of lignin existing in pulp)

c. to partly replace chlorine with chlorine dioxide in chlorine stage

d. to use oxygen in a alkaline stage

(4) To operate the coagulation and sedimentation, and/ or biological treatment in effluent treatment

(5) To dispose of the sludge, in principle, after burning

JAPAN PAPER ASSOCIATION

# WASSERPLANET

1. Jahrgang  
5. Jahrestag  
Freundlich  
2. OM

PLAYBOY  
GREENPEACE

TEMPORAL  
MCM

HÖRZU  
VAL

stern

BUNTE



## Umweltkiller Druckpapier

**COMPETITIVE IMPLICATIONS OF ENVIRONMENTAL REGULATION IN  
THE COMPUTER AND ELECTRONIC COMPONENT  
INDUSTRY**

This case study was prepared by Ben Bonifant, Management Institute for Environment and Business. The research was conducted in collaboration with the U.S. Environmental Protection Agency and Hochschule St. Gallen. Copyright 1994 by MEB. The author gratefully acknowledges the assistance provided by Peter Crawford.

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## EXECUTIVE SUMMARY

### Introduction

Computer and electronic firms were affected by a variety of environmental issues in the late 1980s and early 1990s. Companies in these industries responded to these concerns with innovative programs and technologies. Their experiences support the conclusion that environmental improvement can yield financial improvement. However, they also demonstrate that an industry's structure will critically influence its ability to cost effectively and innovatively comply with demanding regulations.

As the computer and electronics industry grew in the 1960s and 1970s there were few concerns about environmental effects. There were no smokestacks, and from outside appearances the industry was free of the environmental concerns which were becoming important for manufacturers in heavy industries. Outward appearances did not necessarily tell the whole story, however. The processes used to manufacture computers and electronic components required the use of a wide variety of potentially harmful chemicals. If not handled carefully, heavy metals, organic solvents, and noxious gases could be released. Further, the industry's rapid growth had led to a separate set of problems. The growth was fueled by increasing demand for the industry's products. Increasing volumes led to concern about energy use by and disposal of these products.

### Industry Structure

The computer and electronics industry was dominated by U.S. and Japanese firms. In 1992, U.S. firms supplied 62% of the world's computer hardware and 43% of semiconductors. Japanese firms manufactured 30% of computers and 43 % of semiconductors. This left only 9% of the computer market and 15 % of the semiconductor market to be shared by European and Southeast Asian companies. Only in printed wiring boards (PWBs) was there a greater international presence. Here, the U.S. accounted for 29 % of 1992 production, Japan 30%, Europe 16 % , and the rest of the world 25 % .

Governments were intimately involved in the early development and rapid growth of this industry. In the U.S., the unique needs of the Department of Defense spurred (and led to funding for) the earliest computer developments. Later recognizing the strategic importance of the industry, the U.S. government

took a series of reactive measures to protect domestic health in the industry. The Japanese government similarly recognized the strategic value of the industry, but here, the focus was on commercial rather than military concerns. Targeted as a strategic industry, Japanese policy encouraged tariff protection of domestic markets, subsidization and coordination of research, and mechanisms to increase domestic demand. The strategic role in the national goals of the two nations was a subtle but important factor in the development of regulations to address the environmental effects of electronic manufacturing. Neither the U.S. nor Japan was likely to take an extreme position in regulating these industries which was not matched by the other.

Economies of scale and barriers to entry were important to the strategies developed by leading firms in the industry. IBM established a commanding position in the industry in the 1960s by erecting a competitive barrier which significantly increased the cost for customers to change suppliers. The company's System 360 line provided the first family of computers which allowed transfer of software from one system to another. IBM protected its position through substantial vertical and horizontal integration, ultimately supplying most of the electronic components, the software, and the computers themselves. The company became further entrenched in their customer's business by providing leasing arrangements and establishing an extensive service division. Competitors, whether U.S. or Japanese based, found it extremely difficult to break IBM's hold on the market. Only by identifying markets underserved by IBM did firms such as Cray Research and Digital Equipment Corp. capture modest shares of the computer market.

The increasing capabilities of semiconductor microprocessors coupled with a strategic decision by IBM led the company to lose dominance of the computer market. In 1981, the company recognized the growing role of personal computers in the market. Made possible by advancements in microprocessors, these systems were significantly less powerful than anything IBM manufactured. However, entrepreneurial firms such as Apple Computer had begun to reach revenue and income levels which attracted the attention of the large market leader. Rushing to enter the market quickly, IBM bought many of the components for its personal computer from outside suppliers. Notably, it chose Intel Corp.'s microprocessor and Microsoft's DOS operating system. The IBM personal computer quickly gained share and expanded the market segment's size. However, by sourcing components, IBM had left itself open

to competition from “clone” manufacturers, companies which provided a computer which functioned in much the same way the IBM machines did.

Thus, the barriers to entry were substantially reduced in one segment of the market, and a variety of computer manufacturers were established in the 1980s. This, in turn, led to a proliferation of manufacturers farther up the supply chain. Several semiconductor manufacturers were established typically relying on the technical expertise of a founder and financing from a vibrant U.S. venture capital market. Both the computer and semiconductor markets were limited, however, by high capital costs for manufacturing facilities and their reliance on advanced technical knowledge. In the market for printed wiring boards, the manufacturing methods were well understood and capital costs to establish a small manufacturing facility were less than \$1 million. Hundreds of small operations went into business in the 1980s most never achieving revenue greater than \$6 million.

In Japan, the structure of the industry was quite different. Here, there was little opportunity for firms to develop in individual market areas. Large firms such as Fujitsu, Hitachi, and NEC which led in computer markets were highly vertically integrated producing many of their own components. Other firms which supplied the industry were tied closely to the computer manufacturers through intricate strategic alliances.

### **Environmental Issues**

First local and then global concerns tarnished the electronics industry’s clean image. Under the U.S. Federal Water Pollution Control Act of 1972 and the Clean Water Act of 1977 and the Japanese Water Pollution Control Law of 1970, wastewater from electronics manufacturing began to be regulated. Heavy metal contamination in releases from PWB fabrication facilities was specifically targeted for control. Plating and etching operations in these facilities led to high wastewater concentrations of copper, lead, and tin. Companies were forced to install water treatment systems and to take efforts to limit water use.

A second area of concern would lead to substantial control over certain materials used in electronics manufacturing. In the late 1980s concerns about the destruction of the ozone layer emerged as a critical environmental issue. A model had been established linking reduced ozone concentration in the

stratosphere and increasing releases Of chloroflouorocarbons (CFCs) in commercial and industrial processes. These materials were used throughout electronics manufacturing processes, primarily in cleaning and degreasing applications. In 1989, these manufacturers were responsible for 28% of Freon 113 released and 11% of trichloroethane released in the U.S. These two chemicals were among those many researchers had concluded were contributing to ozone destruction.

Finally, the industry was faced with the contribution its products made to the problem of global warming. Increased levels of carbon dioxide in the atmosphere were projected, if left uncontrolled, to lead to higher temperatures on the earth's surface resulting from the "greenhouse effect." Global warming concerns had led to efforts to reduce energy use because electrical utilities burned substantial amounts of coal. Computer use was estimated to account for 5 % of office energy use and was projected to increase to 10 % by 2000. Thus efforts were underway to reduce energy demands stemming from computer use.

### **Competitive Implications of Environmental Regulations**

In the early 1990s, the latter two issues, reduction in energy use and elimination of CFCs from manufacturing were being accomplished with little identifiable effect on competitiveness. Increasing the energy efficiency of the computers themselves was not technically challenging. The U.S. EPA had determined that 30% of computers were left on all of the time, and even those powered only during the day were often left unused. Simply by incorporating logics to power down the computer when not in use, as much as 70% of the energy used could be saved. Technology to accomplish this existed and had been used for several years in laptop computers. Manufacturers explained that energy efficient computers were not marketed because no one had ever asked for them. This changed when the U.S. federal government announced in 1993, that all future purchases of computers would need to meet a minimum set of energy use requirements outlined in the U.S. EPA's "Energy Star" program. Energy efficient computers yielded as much as \$75 in energy savings to computer buyers while requiring no additional costs for the product.

In the case of CFCs, an international organization had been established to cooperatively identify and disseminate methods of production which did not require CFCs. Computer and semiconductor firms were able to use this and other information to rapidly remove CFCs from their operations. Surprisingly, some of the modifications which were made provided attractive rates of return and improved the quality of the

cleaning process. Manufacturers explained that the use of CFCs was so pervasive that operators never questioned the potential for alternative means of production. The financial benefits of the changes were, however, very small when compared to the overall operations of the firms. As a result, managers in these companies chose to publicize their innovations. Greater benefit was felt to accrue through the publicity benefits than would be lost by failing to protect an innovation.

For printed wiring board manufacturers, no means of production had been identified which made it financially attractive to eliminate heavy metals from wastewater. However, innovative firms had found methods of substantially reducing the cost of dealing with releases, many of which depended on reducing the amount of metal released. Programs had been established by a wide variety of regulatory, public interest, and industry organizations to disseminate technologies which would allow firms to reduce their waste and lower their pollution abatement costs. Smaller firms were less able to absorb the vast amounts of information available and also were less able to undertake necessary capital projects than their larger rivals. As a result, smaller firms faced higher relative pollution abatement operating costs and environmental equipment made up a large share of their assets. These factors support the industry assertion that environmental regulations were accelerating the consolidation of the industry. These results indicate that creative methods are necessary when environmental regulations are developed for fragmented industries. Otherwise, those firms which are smaller than their rivals, but large enough to materially contribute to the environmental problem will suffer disproportionate effects of the regulation.

## INDUSTRY STRUCTURE

### Product

#### Product Description

In 1992, the world market for computers had reached \$114 billion.<sup>1</sup> Providing a means to store, retrieve, and manipulate data, the market ranged from low powered personal computers designed for word processing and light analytical applications to sophisticated supercomputers built with associated software allowing rapid completion of massive numbers of individual calculations (see tables 1-2 for a breakdown of markets). Every computer had at its heart one or more microprocessors with circuit patterns allowing data control and processing. These devices were called semiconductors because the useful characteristics of the materials were based on their ability to conduct charge across gates only when signaled to do so. Computers operated by providing a means to control the signals and a method of interpreting the resulting currents.

Computers stored data in memory chips. These devices were also semiconductors based on similar materials and technologies as microprocessors but relying on different types of designs. Electrical signals and power were carried within the computer through a series of printed wiring boards (PWB). PWBS were typically epoxy-glass boards on which had been patterned an intricate design of copper traces which carried current.

For the most part, the microprocessor was accessed through keyboard input and video display output. In addition to these components, computers included longer term memory storage devices (disk drives) and power supply units. Additionally, connectors were incorporated which allowed linking with additional input or output systems such as modems, printers, or data collection sensors. In some cases, these devices were included within the housing of the computer.

### Substitutes

When the broad market of computers is considered, there were few substitutes for the products of the

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1. U.S. International Trade Commission, "Global Competitiveness of U.S. Advanced-Technology Industries. Computers," Investigation No. 332-339, December 1993

industry. However, within the industry dramatic changes in markets had occurred as a result of substitution of one type of product in the markets of another. This flow of markets among segments had characterized the industry since its inception as new manufacturers entered the market by exploiting niche opportunities. These niches then, in many cases, expanded to a point where further segments could be targeted by additional entrants to the market.

In the 1950s and early 1960s a wide variety of computers were sold by a number of competitors. However, IBM dominated the market with sales which were almost ten times those of its closest rival.<sup>2</sup> In 1965, IBM introduced the System 360. For the first time a company offered several computers of differing performance which could all use the same software. The System 360 and subsequent 370 series became the standard computer architecture providing IBM with market shares of nearly 70% in the late 1960s.

Competitors hoping to enter the market searched for unique ways to address the special needs of niche market segments. Control Data and Cray Research, for example, served the high end of the market by introducing supercomputers in the early 1970s. On the other end of the market, DEC (Digital Equipment Corporation) was among the first companies to target a growing niche of the market when it introduced the first minicomputer in 1963. This product took market share away from IBM by addressing the needs of technically sophisticated users who desired access through time sharing arrangements.<sup>3</sup> It also dramatically expanded the market by providing a product to smaller organizations unable to justify the capital expense of the larger machines.

Apple Computer introduced the first commercially successful personal computer in 1977 taking advantage of significant advances in microprocessor capabilities. The company was able to reach sales nearing one half billion by 1981 when IBM turned its attention to this segment of the market. By 1985, IBM had far surpassed its rivals in personal computers achieving a market share in excess of 40%. However, it then

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2. Flamm, Kenneth, Creating the Computer. Government, Industry, and High Technology, The Brookings Institute, Washington, D.C. 1988

3. U.S. International Trade Commission, "Global Competitiveness of U.S. Advanced-Technology Industries: Computers," Investigation No. 332-339, December 1993

faced a new type of challenger. Instead of aiming at underserved niches of IBM's market, new competitors attempted to be as much like IBM as possible. Clone manufacturers led by Compaq and followed by AST Research, Dell, and Gateway 2000 eroded IBM's market share to less than 12% by 1992 (see table 3).

### **Production Process**

The computers of the early 1990s were complex devices which functioned through the coordinated interaction of several distinct components. Manufacturers varied significantly on their level of integration in the production of these components. Some, like Gateways 2000 or Dell, performed only the final assembly stages of production. By contrast, several Japanese manufacturers had integrated far upstream completing many operations in-house which most U.S. manufacturers purchased from outside suppliers.

Three areas of the production process are particularly important to this discussion, semiconductor manufacturing, printed circuit board manufacturing, and mounting of sub-components on the printed circuit board. These steps represent only part of the overall computer manufacturing process. In this discussion, semiconductor manufacturing will be considered the first step in the computer production process. Upstream of this process, of course, manufacturers prepared materials and equipment used in semiconductor production. Beginning with pure silicon wafers, semiconductor manufacturers imprinted extremely fine circuits on the material and packaged the resulting product in plastic or ceramic casings. Similarly, printed circuit board manufacturers, produced a pattern of copper traces on a base material (also called a substrate and typically made of epoxy glass laminate). The packaged semiconductors and other electronic sub-components were mounted on the printed circuit board. Final assembly of the computer involved attaching several of these boards and other components - disk drives, keyboards, and monitors, which also contained printed circuit boards - into the product.

Manufacturing of semiconductors and printed circuit boards relied on photolithographic processes to produce circuit patterns. In semiconductor manufacturing, the objective was to selectively create

impurities onto a layer of silicon dioxide.<sup>4</sup> Areas which had impurities introduced were said to be doped. By patterning the pure and doped areas of the silicon dioxide, the desired electrical performance was achieved.

The process required first growing a layer of silicon dioxide on the surface of the wafer. Then, a material known as a photoresist was applied to the surface. This was an organic material which was sensitive to ultraviolet (UV) light. Once exposed to W light, the substance reacted to form a hard solid material. The area which was not exposed could be removed using a solvent of either organic or aqueous nature. By controlling the areas which were exposed, and then removing the unexposed material, a pattern of photoresist was created on the surface of the silicon dioxide. The next step was to etch away the unprotected silicon dioxide and expose the underlying silicon to dopant (usually phosphene or arsene). Then, the photoresist could be removed and additional layers of silicon dioxide could be grown over the entire surface of the wafer. The process of coating, exposing, dissolving, and etching was repeated many times in wafer manufacturing.<sup>5</sup>

After the semiconductor wafer was manufactured, it was packaged, a step in which the individual dies (chips) were sliced off of the large wafer, encased in plastic or ceramic for protection, and connected to metal lead frames that would link the chip to the printed circuit board.<sup>6</sup> The steps involved in packaging the semiconductors and the subsequent testing steps were significantly more labor intensive than the preceding fabrication processes (which required significant capital and technological investment). As a result, the later steps were often transferred to lower cost labor production areas, notably Southeast Asia<sup>7</sup>

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4. A very small part of semiconductor manufacturing used germanium, gallium arsenide, or indium phosphide. These materials provided faster performance or other desirable properties but at higher cost or with trade-offs in other properties. Additionally, production methods had focused on continually improving silicon based systems. As a result, gallium arsenide semiconductors were produced for a very small part of the market for specialized military and high performance applications.

5. Weste, Neil and Kamiran Esbroughian, Principles of CMOS VLSI Design. Addison Westly, 1988 Chapter 3.1

6. Microelectronics and Computer Technology Corporation, Environmental Consciousness: A Strategic Competitiveness Issue for the Electronics and Computer Industry. Austin, 1993 p. 129-132

7. USITC, Industry & Trade Summary: Semiconductors (USITC publication 2708) December, 1993.

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Like semiconductors, printed circuit boards performance relied on the patterning of one material with certain electrical characteristics within another material with differing electrical performance. Printed circuit boards used conductive copper layered over a base material made of an insulating substance. This base material (also called a substrate or dielectric) was usually made of an epoxy glass composite.<sup>8</sup>

Manufacturers received the substrate which had already been laminated with a thin (.001" - .002") layer of copper foil. Holes were drilled in these boards which would later allow current flow from one side of the board to the other (more than 90% of the boards manufactured in the U.S. in 1990 were either double sided or multilayer meaning that copper circuitry was patterned on both faces of the board). Then, the board was exposed to an electroless copper addition process which initiated a copper surface on the hole walls. The boards were then coated with a photoresist material similar to that described for use in semiconductor manufacturing.<sup>9</sup> A pattern was exposed on the photoresist which covered the area of the board on which no copper would ultimately exist. More copper was deposited using an electrolytic deposition.<sup>10</sup> The copper which had been built up in the electrolytic process was then protected through the deposition of a material which was resistant to a copper etchant (usually tin or tin/lead). The photoresist material was then stripped away, and the underlying copper was etched from the surface. This left a pattern of the electrolytically deposited copper protected by the tin/lead etch resist,

A chemical process was used to remove the tin/lead and expose the conductive copper. A protective coating called a solder mask (similar to the photoresist) was then layered on the board. Holes were left in the solder mask which allowed application of solder (tin/lead) on the contact areas of the board. Areas which might experience frequent abrasion, particularly contact surfaces, were often then plated with nickel or gold for protection.

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8. The explanation of the production of printed wiring boards draws on the explanation provided in Printed Circuit Board Basics, Michael Flatt, Miller Freeman 1992, San Francisco

9. By the early 1990s, dry film photoresist had become the primary type of imaging resist. This type of resist was applied to the copper surface in a simple laminating step. Previously, photoresist had been screen printed on the surface of the copper. A new system, liquid photoresist was beginning to be more widely used in the early 1990s because of its performance in manufacturing boards requiring very thin line width (less than .005").

10. Two separate plating processes were required because the electrolytic deposition of copper will only occur on conductive surfaces. The electroless process provides this conductive surface on the through hole walls, while the electrolytic process increases the copper thickness on all exposed areas.

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Printed circuit board manufacturers typically provided boards in this solder mask over bare copper (SMOBC) condition. Then either the final producer or a different intermediary manufacturer would mount sub-components on the board. This process was called “stuffing” or “assembly” and two primary methods were employed. In one, sub-components were surface mounted by being placed on contact points and connected through reflow of solder material. In wave soldering, sub-components were inserted through the board and a wave of solder was passed against the pins thus making a connection. In both surface mount technology and in wave soldering, a solder flux was used to facilitate solder attachment of the sub-components. After soldering, the rosin portion of the solder flux typically had to be removed in a cleaning process.

### **Economies of Scale**

The economies of scale in semiconductor manufacturing have been well documented. Scale economies were encountered in both greater distribution of fixed costs and in more rapid acquisition of learning. The high level of capital costs associated with fabrication facilities made operating at maximum production levels a critical target for manufacturers. Extremely high research and development costs associated with semiconductor design also drove scale economies. By one estimate, there was an approximately 90% scale relationship, meaning that for every doubling of the size of a production facility, the unit costs were reduced 10% .<sup>11</sup>

Learning also drove important scale economies in semiconductor manufacturing. As a firm produced a new chip or worked within a new facility, it acquired skills specifically associated with that production. Yields improved and costs reduced. Although flattening somewhat in the late 1980s, the learning effect was traditionally expected to provide a 30% reduction in costs for each doubling in cumulative volume of chips produced.<sup>12</sup>

In printed wiring board manufacturing, scale economies were not as great, but could make the difference between profitability and losses. The primary areas of scale advantage for the largest firms were in

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11. “Sherman, Stratford, “The New Computer Revolution, \* Fortune. June 14, 1993. p. 68

12. Semiconductor Industry Association, “The Impact of the 1986 U.S. -Japan Semiconductor Agreement on DRAM Prices.”

greater spreading of selling expenses and of administrative expenses. For the smallest firms scale drove additional disadvantages in costs for buildings and machinery, inspection labor, and non-direct manufacturing labor such as inspection.

### **Entry and Exit Barriers**

As discussed above, IBM Created a high entry barrier to other firms by achieving an industry standard with the introduction of its System 360 line of computers. Other firms only got around this barrier by providing products which were SO compellingly suited to the customer's needs that they were willing to learn a new standard. A new type of entry was encouraged, however, in the personal computer market once standards were established but not controlled by IBM.

IBM joined the personal computer market in 1981. In contrast to its strategy in mainframes (where IBM produced almost all of the components as well as providing software and servicing), the company made a strategic decision to purchase critical parts of the product from outside suppliers. In particular, IBM turned to Intel for the critical microprocessor and to Microsoft for operating software. Using outside suppliers allowed IBM to reach the market in 13 months and rapidly achieve a 40% market share.<sup>13</sup>

The strategy to use outside suppliers for critical components had unintended consequences on the competitive nature of the personal computer market for years to come. Other manufacturers were able to copy the IBM machines providing "clones" which to the user operated virtually identically to the IBM products. Initially, clone manufacturers such as Compaq achieved rapid growth simply by undercutting IBM's prices. Unburdened by large overheads and free of the costs associated with developing the standards for the product, early clone manufacturers found ample opportunity to beat IBM's cost position while still closely following the large company's lead in manufacturing strategy and distribution channels. Later entries to the clone competition found success by locating labor intensive operations in low wage countries or by eliminating distribution costs through direct marketing.

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13. Carroll, Paul, Big Blues, Crown Publishers, Inc., September, 1993

Barriers to entry in component manufacturing varied enormously. In semiconductor manufacturing there were many while in printed wiring boards there were few. Semiconductor fabrication plants were being built at a cost of over \$1 billion in the early 1990s. In the microprocessor segment of the market, large development costs also dissuaded new entrants. Additionally, software had been designed to work with existing (primarily Intel's) microprocessors providing another barrier. In 1990, Intel had achieved a 53 % market share of microprocessors.<sup>14</sup> As a result, competitors such as Advanced Micro Devices were forced to follow Intel's lead in microprocessor design. In response, Intel jealously guarded development secrets, aggressively litigated patent claims, and accelerated development times in an effort to stay ahead of following competitors.<sup>15</sup> In 1993, Apple, Motorola, and IBM were attempting to challenge Intel's dominant position in microprocessors by designing and marketing an alternative chip called the PowerPC. Only by combining the capital access, design experience, and production skills of these three large firms could a credible challenge to Intel's position be made.

In memory chips, the entry barriers were also formidable. Again, the high cost of fabrication facilities discouraged most competitors. More important, however, were the large learning advantages which were held by firms which had experience in manufacturing memory chips. Incorporating learning effects into strategic behavior had been an important characteristic of competition in the memory chip market. Prior to 1986, Japanese manufacturers sold 64K memory chips in the U.S. at a price which was determined to be below the cost of production.<sup>16</sup> Facing foreign competitors who were unconcerned with short term results, such U.S. firms as Intel and Fairchild exited the market. Later, the U.S. Department of Commerce began to assess antidumping duties on the Japanese manufacturers. It appears, however, that the U.S. firms had fallen too far behind to reenter the market for memory chips. In 1986, only two U.S.

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14. Dataquest data included in Tyson, Laura D'Andrea, "Managing Trade and Competition in the Semiconductor Industry, " in *Who's Bashing whom?*, Institute for International Economics, Washington, D.C., 1992

15. "Intel: The Coming Clash of Logic," *The Economist*, July 3, 1993

16. USITC, 64K Dynamic Random Access Memory Components From Japan (investigation No. 731-TA-270, USITC publication 1862, June 1986.

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merchant firms continued to produce the state of the art 256K memory chip; eleven firms had produced 16K memory chips in 1980.<sup>17</sup>

In contrast to semiconductor manufacturing, barriers to entry in printed wiring board production were very low. A small PWB shop could begin operation with less than \$1 million in equipment. In addition, the manufacturing technology was well understood, and design skills were not required (designs were supplied by the customer). Not surprisingly, PWB manufacturing was crowded with small operations, although consolidation was underway.

## **Buyers**

### **Buyer Description**

The segmentation of the computer market resulted from companies specifically designing the products' performance for the needs of targeted customer groups. Supercomputers were developed for the rapid calculation requirements of the government and research organizations and the markets for these devices remained in those areas. Mainframes and workstations were developed for specific areas of business computing (accounting and technical) and these continued to be the dominant customers of these suppliers. Personal computer markets were somewhat more diverse, but even here, business applications accounted for more than two thirds of sales. Educational applications and scientific users each accounted for 10% of the market, and the remaining sales were made to home users.<sup>18</sup> Dramatic price cutting by personal computer manufacturers in 1993 was anticipated to increase sales to all market segments, but home users were expected to experience the greatest relative increases.

Computer manufacturers were important, but by no means the only buyers for semiconductors and printed wiring boards. Telecommunications, consumer electronics, industrial instruments, automobile manufacturing, and military devices were other important markets for electronic components (see table 1). In Japan, the markets for consumer electronics were particularly important to the upstream suppliers

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17. Howell, Thomas R., et.al., Creating Advantage: Semiconductors and Government Industrial Policy in the 1990's Semiconductor Industry Association, 1992

18. U.S. Department of Commerce, International Trade Administration, "U.S. Industrial Outlook 1993," 26-15

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for computer manufacturers while in the U.S., the high level of demand for military devices supported many of the developments in semiconductors and PWBs.

### **Distribution Channels**

One of the critical areas of strategic competition in the computer market occurred in companies' selection of distribution channels. Three primary means of distribution were used, direct selling, intermediary sales, and mail order.

There were four primary types of intermediaries used by computer manufacturers, dealers, retailers, intermediary mail order houses, and value-added resellers. The largest of these channels, the dealers, dominated this segment with 44% of 1993 sales. Retailers, including such operations as superstores and mass merchandisers held 19% of the intermediary sales but were expected to grow with increasing home computer sales. Mail order and value-added resellers contributed 17 % and 15 % respectively.<sup>19</sup>

### **Suppliers**

Computer manufacturers had varying strategies concerning making or buying critical components. In the U.S., some manufacturers such as Apple or Compaq outsourced virtually all components while others, notably IBM, continued to produce many components in-house.<sup>20</sup> Japanese companies were much more integrated upstream than typical U.S. manufacturers. Hitachi, for example, not only produced its own semiconductors, but had operations producing semiconductor manufacturing equipment including steppers, ion implanters, and dry etchers.

Important suppliers to the U.S. computer industry included semiconductor manufacturers, printed wiring board manufacturers, monitor producers, and molders for plastic housings. Farther upstream were suppliers of semiconductor equipment, printed wiring board equipment, and chemicals. These markets could be broken down into the following categories:

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19. Pope, Kyle, "Forecasts Aside, Dealers of PCs Thrive Again.' Wall Street Journal, February 1, 1994

20. The USITC estimated that IBM held an 11.2% share of the semiconductor market through captive sales. All other captive production was estimated to be 4.6% of the market. In printed wiring boards, the IPC estimated that captive manufacturing made up 31% of the 1992 market with ten manufacturers making up 67% of this.

Semiconductor Equipment: Equipment for semiconductor manufacturing was broken down into three primary areas wafer processing, assembly, and testing. World sales of semiconductor equipment were \$8.5 billion in 1989 with more than 50% of this (\$4.5 billion) occurring in the wafer processing area.<sup>21</sup> Devices used in wafer processing were based either on ultra pure chemical processes (diffusion and ion implantation equipment) or on Precise control of exposure to light (photolithographic equipment). Assembly equipment, on the other hand, required design of instruments for high tolerance mechanical processes which allowed rapid bonding of thin wires. Finally, testing equipment demanded the development of means for the automated analysis of semiconductor performance.

Semiconductor Materials: Although processing materials made up the largest part of semiconductor material sales at \$4.7 billion in 1989, packaging material suppliers accounted for a significant \$3.6 billion in sales. Processing materials included all items used in achieving the basic circuits on the chip and included \$2.0 billion in silicon wafers, \$1.1 billion in photomasks, and an additional \$1.6 billion of other chemicals and materials. Items used in encasing the chip in ceramic and attaching wire fingers later used to electronically connect the semiconductor to a printed circuit board made up the market for packaging materials.<sup>22</sup>

Printed Wiring Board Equipment: Equipment for printed wiring board manufacturing was much less sophisticated than that used in producing semiconductors. Additionally, PWB production was less capital intensive yielding a smaller overall market. In the U.S., PWB manufacturers had capital expenditures equal to 4.9% of their sales in 1991. This resulted in spending of only \$310 million.<sup>23</sup>

Printed Wiring Board Materials: In the U.S., supplies to PWB manufacturers made up a \$1.5 billion market in 1992. The base products made up the largest share of this market with \$664 million in

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21. USITC, Global Competitiveness of U.S. Advanced-Technology Manufacturing Industries: Semiconductor Manufacturing and Testing Equipment: Report to the Committee on Finance, United States Senate (investigation No. 332-303 (final)), USITC publication 2434, September 1991.

22. USITC, Global Competitiveness of U.S. Advanced-Technology Manufacturing Industries: Semiconductor Manufacturing and Testing Equipment: Report to the Committee on Finance, United States Senate (investigation No. 332-303 (final)), USITC publication 2434, September 1991.

23. U.S. Department of Commerce, "1991 Annual Survey of Manufacturers"

laminates and \$115 million in prepreg. Chemicals of various types made up the remainder of PWB material purchases.

## **Environmental Regulation**

### **Environmental Risk Analysis**

In the late 1980s and early 1990s environmental concerns began to be felt throughout the operations of computer manufacturers. Every department, from design to manufacturing to sales to legal faced increasing concerns associated with how their company's current and previous operations were affecting the environment. These concerns can be grouped according to the following four categories:

- \* Contamination of sites from previous manufacturing activities
- \* Chemical releases from on-going manufacturing
- \* Product energy use during operation
- \* Product disposal

#### Contamination From Previous Activities:

The computer industry was highly sought after by communities such as Silicon Valley and Boston's Route 128 area when it began to take off in the 1970s. It attracted high wage jobs, it was growing rapidly, and the processes used were viewed as "clean technologies." There were no smoke stacks like those associated with heavy industry.

Computer manufacturing, in fact, could be a very clean industry. However, the many processes used in putting together electrical components required the use of a wide variety of chemicals. Most of these chemicals did not become part of the final product, so, once used, they had to be removed from the manufacturing site. One particular procedure which caused a number of later problems was the storage of used chemicals in underground storage tanks prior to collection and disposal. Many of these tanks were later found to have been leaking, potentially allowing organic solvents to enter groundwater.<sup>24</sup> While most of these tanks had been removed by the early 1990s, plumes of contaminants remained in the groundwater leading many surrounding areas to be identified on the National Priority List (NPL) of the

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24. Howe, Charles, "Poison in Paradise," Datamation. August 15, 1984

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U.S. EPA Superfund program. More sites were listed on the NPL from California's Santa Clara County than any other county in the U.S. Of the 29 sites, 23 resulted from activities in the electronics industry<sup>25</sup>

#### Chemical Release From On-Going Manufacturing:

The complex processes used to manufacture a computer demanded repeated operations where materials were selectively applied or removed. These processes employed a wide range of chemicals including caustics, heavy metals, and organic solvents. In particular, large amounts of chemicals were used in manufacturing components. Companies making components faced strict chemical use and disposal regulations throughout the U.S., Europe, and Japan and some regulations were particularly severe in California and Massachusetts, the areas in the U.S. where important clusters of these industries operated. In the early 1990s, four areas of chemical use were particularly important for environmental reasons.

- \* Release of metals from plating and etching operations in PWB manufacturing
- \* Release of organic solvents from PWB developing and stripping operations
- \* Release of organic solvents from cleaning operations in semiconductor fabrication
- \* Release of organic solvents from cleaning during board assembly (stuffing)

The goal of making a printed wiring board was to leave a thin trace of conductive material on a non-conducting surface. This was primarily done in a negative process which began with a solid copper film laminated on a glass/epoxy board. Because the trace was made by removing the unwanted copper, large quantities of metal needed to be removed from the manufacturing site. The wastewater from the etching baths typically had copper in such high concentrations that it was economically efficient to retrieve the material. Suppliers recognizing this opportunity had created systems which assisted PWB manufacturers in disposing of their wastewater. Companies such as World Resources Inc., for example, supplied sulfuric acid for etching the copper boards and then later collected the companies' process baths.

Many waste streams in PWB manufacturing were contaminated with metals but were not of sufficient concentration to make reclamation economic. In particular, plating bath and rinse waters from such areas as through hole and connector plating had levels of copper, lead, and tin which were too high for release

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25. Smith, Ted and Woodward, Phil, "The Legacy of High Tech Development," Silicon Valley Toxics Coalition, January, 1997

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in municipal systems, and too low to justify retrieval. Manufacturers were required to treat these streams lowering metals concentration prior to release.

Organic solvents used in developing and stripping early photoresist materials also posed an environmental concern for PWB manufacturers. In producing PWBs, photoresist films were layered on the copper surface of the copper-epoxy/glass laminate. The patterns which would eventually become the copper traces were then made through patterning on the photoresist by exposure to light (areas exposed became hard while unexposed areas remained unpolymerized). The photoresist was developed by removing the unexposed area.

Components were attached to the PWBs in a process called “stuffing or “assembly.” Here components were placed on the board surface and electrical connections were made by soldering. In order to make a good solder connection, a flux material was used. This tacky, rosin like, material contained chemicals which reacted when heated with the oxidized layers of the metal surfaces exposing fresh area for a strong solder bond. After soldering, though, the flux had to be removed because it was felt to be a contaminate which could later damage the performance of the component. Prior to efforts to reduce their use, chloroflourocarbons (CFCs) were almost universally used to remove solder flux. This use and other cleaning operations in board manufacturing, chip fabrication, and other production operations made electronics manufacturers among the largest users of CFCs. As shown in table 13, the 1989 EPA inventory of U.S. toxic releases (TRI) indicated that 28% of Freon 113 releases, 11% of trichloroethylene releases, and 11% of 1,1,1 trichloroethane releases resulted from electronics facilities.<sup>26</sup>

CFCs had received widespread attention because of the role many researchers had concluded they played in the destruction of the earth’s stratospheric ozone layer. The ozone concentrated in a band 10-50 km above the earth’s surface absorbed W-B radiation (ultraviolet light in the band between 280 and 315 nm). In the early 1990s, atmospheric scientist had concluded that the earth’s surface was receiving increased levels of W-B. They estimated that increases were occurring at a rate of 5 % to 11% per decade in the northern hemisphere while in the southern hemisphere, increases of up to 40% per decade

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26. U.S. EPA, Toxic Release Inventory

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were occurring.<sup>27</sup> Scientist had further concluded that the reductions in ozone which allowed this increase in UV-B could themselves be caused by increased releases of CFCs.<sup>28</sup> CFCs were very stable compounds; so stable, in fact that they were not broken down by the natural processes that removed chemicals from the lower atmosphere. As a result, CFCs migrated to the upper atmosphere where over many years they were slowly broken down by solar radiation. The breakdown of CFCs released chlorine which then, through a series of chain reactions, broke down large quantities of ozone.

#### Product Energy Use During Operation:

Computer systems were estimated to account for 5 % of commercial electricity consumption in 1993 and usage rates were growing rapidly.<sup>29</sup> However, much of the energy used in office computer systems was wasted. Researchers had found, for example, that 30% of all computers were left on overnight. When a computer was left on at all times, energy costs were estimated at \$105 while those that were turned off after working eight hours led to energy costs of only \$35 annually.<sup>30</sup> Although screen saver programs (software which replaced an idle screen with images of swimming fish or flying toasters) had become popular, these products did nothing to lower the energy demands of the computer. The U.S. EPA estimated that more than \$2 billion of energy was wasted on idle computers. Producing this energy contributed to global warming through carbon dioxide emissions and to acid rain through the releases of sulfur and nitrogen oxides. Surprisingly, despite the obvious potential savings to their customers, computer manufacturers were being compelled to develop energy efficient computers because of environmental concerns and not because customers viewed the energy savings as a feature which they valued.

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27. Madronich, S., et. al. , "Changes in Biologically Active Ultraviolet Radiation Reaching the Earth's Surface," in United Nations Environment Programme, Environmental Effects of Ozone Depletion: 1991 Update, November 1991

28. The story of how scientist and policy makers finally began to act on the conclusion that CFCs caused ozone destruction is a long and interesting one. The brief treatment included here is drawn from Ozone Diplomacy, Richard Eliot Benedick, Harvard University Press, Cambridge MA, 1991

29. U.S. EPA, Information Flier, "EPA Energy Star Computers," October 14, 1993

30. Nadel, Brian, "The Green Machine," PC Magazine, May 25, 1993

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### Product Disposal:

Computer manufacturers competed by providing increasing memory storage and calculation speeds to their customers. Advancements in hardware encouraged software developers to provide more features which only worked on the more powerful machines. As a result, computers users were enticed to upgrade often. Older equipment became obsolete in a matter of a few years. Some of this equipment was transferred to areas of the customer's organization which did not require the latest technology, some equipment was sold at steep discount on the second hand market, and still other equipment was donated to schools and civic groups. However, eventually all of this equipment required disposal and although electronic equipment had not been classified as a hazardous waste, manufacturers were concerned about their responsibility for disposal of products containing heavy metals and other contaminants. Concerns with disposal loomed in the future for most computer manufacturers in 1993, and did not significantly affect their companies' product design or manufacturing operations. However, at that time managers were beginning to consider how they might be strategically affected by new regulations on disposal. Among these, a German initiative requiring companies to "take back" their products after use was receiving considerable attention.<sup>31</sup>

### Severity and Impact of Regulation

Manufacturers of electronic devices faced a variety of environmental regulations. Manufacturing areas were given limits on allowable releases of materials in their air and water discharges and in some cases, they were prohibited from using certain materials in production. As a result, facility managers had to consider environmental compliance among the many issues materially affecting the financial performance of their operations. As discussed above, companies which produced electronic components were relatively more affected by environmental concerns than were those firms which provided completed electronic devices.

In 1991, computer manufacturers in the U.S. reported that environmental abatement and control capital expenditures made up a modest 0.9% of all capital expenditures (similarly communications equipment

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31. Cartron, Dominique, "Global Environmental Regulations and Their Effect on the Electronics Industry," The Microelectronics and Computer Technology Corporation, Austin, Texas, 1993

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Suppliers reported 0.5 % of capital expenditures went for pollution control equipment - see table 14).<sup>32</sup> Operating costs were similarly low at 0.1% of the value of industry sales. Semiconductor manufacturers were more affected with 3.6% of capital expenditures (\$106.2 million) spent on pollution control equipment and environmental operating costs at 0.4% of sales.<sup>33</sup>

The ability to control environmental costs was critical to PWB manufacturers. In the U.S. in 1991, 5.6% of capital spending in this industry went toward pollution abatement and control. Operating costs amounted to 1.3 % of sales.<sup>34</sup> The great majority of these costs were associated with treating wastewater prior to release. For example, industry groups estimated that spending for wastewater treatment chemicals was more than \$40 million which would account for more than half of the total reported operating costs for environmental control .<sup>35</sup> The effect on small firms was reported to be greater relative to their sales than that on larger firms. For example, environmental control equipment was estimated to represent 9.6% of the capital expenditures of firms with less than \$6 million in sales between 1991 and 1994 while the same category of equipment made up only 5.9% of the capital expenditures of firms with greater than \$30 million in sales.<sup>36</sup>

The costs described above capture only those from on-going production and do not include the entire effect of environmental regulations in the industry. All areas of electronics manufacturing were affected by environmentally driven limitations on materials used in production. Responding to evidence that chloroflourocarbons destroyed ozone in the stratosphere, eighty-one nations (as of December 1991) had accepted the Montreal Protocol calling for the total elimination of the substances by the year 2000 (the Montreal Protocol is discussed further below). Manufacturers were forced to find alternative methods

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32. U.S. Department of Commerce, "Current Industrial Reports, Pollution Abatement Costs and Expenditures, 1991."

33. U.S. Department of Commerce, "Current Industrial Reports, Pollution Abatement Costs and Expenditures, 1991."

34. U.S. Department of Commerce, "Current Industrial Reports, Pollution Abatement Costs and Expenditures, 1991."

35. The Institute for Interconnecting and Packaging Electronic Circuits (IPC). "TMRC Analysis of the Market, Rigid Primed Wiring Boards and Related Materials for the Year 1992," June 1993

36. The Institute for Interconnecting and Packaging Electronic Circuits (IPC)

of production eliminating the widespread use of CFCs in solvent and cleaning processes. This required expenditures for research into new manufacturing techniques as well as evaluation of substitute materials. Suppliers also carried research costs as they searched for alternative materials which could be used by the industry. Additionally, those firms that had been identified as “potentially responsible parties” at Superfund sites experienced substantial costs. The average cost of cleaning up a Superfund site was \$20 to \$30 million during this period with comparable additional costs associated with the legal fees incurred as firms argued over the share of the cleanup costs to be borne by each party.

## COMPETITION

### United States

#### Competitiveness Overview

Firms based in the United States held a 61% share of the \$114 billion global computer hardware market in 1992. This strong position represented a very modest drop from the U.S. share of 63% in 1988. In every market segment from personal computers to workstations to supercomputers, U.S. firms led the world market (tables 1-6). United Nations trade statistics (based on site of manufacturing not location of headquarters) indicate a similarly strong position for the U.S. in this industry. In 1990, the U.S. maintained a trade surplus of more than \$4 billion in computers and central processing units. Decentralized manufacturing by U.S. firms made the share of world exports significantly lower than the share of total production, but even here, the U.S. led with a 30% share.<sup>37</sup>

The U.S. position in electronic components was also strong but was by no means dominant. In 1992, U.S. based suppliers produced 42.6 % of semiconductors.<sup>38</sup> Semiconductor market shares had swung widely during the 1980s. In the early part of the decade, U.S. firms had dominated, producing more than 60% of all semiconductors. Then, as Japan took an increasingly important position in the supply of memory (specifically dynamic random access memory or DRAM) chips, the U.S. share had fallen below 40% in the middle of the 1980s.<sup>39</sup> Many industry analysts viewed the strength of the U.S. industry in the early 1990s as a sustainable position which would grow through the end of the decade.<sup>40</sup>

Globalization of operations had a significant impact on export positions of U.S. firms in semiconductors. United Nations data show that in 1990, producers operating in the U.S. exported \$11.5 billion in

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37. United Nations, "UN Trade Statistics Yearbook, 1990"

38. The USITC reported data based on location of manufacturing operations rather than the nationality of the firms headquarters. Using this measure, U.S. production of semiconductors was slightly less than 30% in 1992, with Japanese facilities responsible for approximately 35% of production.

39. Howell, Thomas R., et.al, Creating Advantage: Semiconductors and Government Industrial Policy in the 1990s Semiconductor Industry Association, 1992

40. Market share projections by VLSI Research put the U.S position above 50% by 2000

semiconductors making up 26.7% of world exports. The U.S. was also the largest importer of semiconductors with \$10.6 billion of product being brought into the country.<sup>41</sup> Much of this trade, however, was within companies with base semiconductors being manufactured in the U.S., and then shipped to lower wage countries such as Singapore and Malaysia where labor intensive packaging and testing operations were completed. Data from the U.S. Department of Commerce highlight the impact of semiconductor parts exports showing that more than half of U.S. semiconductor exports were in the form of parts between 1986 and 1992.<sup>42</sup>

U.S. firms produced 29.2 % of the world's printed circuit boards in 1992. As in other categories of electrical components, exchange rate fluctuations had a significant effect on the comparable positions of the major supplying nations. A comparison can be made between 1987 and 1992 when exchange rates between the U.S., Japan, and Germany were similar. In those years, Japan's share of world PWB production remained approximately 30%. The U.S. had gained more than a share point increasing from 28 % to 29.2 % , and European manufacturers had lost more than 3 share points falling from 18.6% to 15.6% of world production.<sup>43</sup>

### Leading Firms

Although the company experienced severe financial difficulties in the early 1990s, IBM remained by far the world's largest supplier of computer equipment. In 1992, IBM shipped more than \$28 billion in hardware to its customers. The company supplied all areas of the hardware market with the dominant position in mainframes, the leading share of personal computer sales, the second leading share in supercomputers, and the third leading position in workstations (see tables 3 through 6). No other company participated in all four areas. Additionally, IBM achieved only 44% of its revenue from

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41. United Nations, "UN Trade Statistics Yearbook, 1990"

42. USITC, Industry & Trade Summary: Semiconductors (USITC publication 2708) December, 1993. Department of Commerce data differs from United Nations data showing a significantly higher level of imports. As a result, although the UN data indicate a trade surplus of \$800 million in semiconductors for the U.S., the Department of Commerce reported a trade deficit of \$1.3 billion. While the reason for these differences is not clear, it is evident that the U.S. maintained a significant trade surplus with the European Community and had a large trade deficit with Japan and Korea. Unfortunately, neither data source breaks down semiconductor trade into subcategories.

43. The Institute for Interconnecting and Packaging Electronic Circuits, "TMRC Report on the World Market for Printed Wiring Boards and Substrate Materials for 1992., Chicago, 11, June 1993

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hardware operations; 18% came from software, 25% from service operations, and 14% from other areas such as typewriters.

Other leading U.S. computer firms had typically achieved their positions by identifying and developing a market area which IBM did not target. DEC in minicomputers and Cray Research in supercomputers represent examples of firms which were able to grow rapidly in the 1960s by targeting specific customer needs. In the late 1970s and 1980s Apple developed a new market on the low end of users needs when it introduced its personal computers and further expanded the market with the 1984 introduction of the Macintosh. Sun Microsystems provided more power to individual users through the introduction of the workstation in 1985. The pioneering work of these and other firms brought them periods of terrific financial success. Other firms rapidly followed their lead (and IBM inevitably entered the market area in which it had previously not participated) rapidly making each new segment of the computer industry very competitive.

In the U.S. computer manufacturers relied on suppliers for critical components. Intel, the producer holding more than 50% share of the microprocessor market, was critically important to the health of the U.S. computer industry. By providing increasingly powerful and fast microprocessors, Intel expanded the capabilities of personal computers. Other microprocessor firms such as Advanced Micro Devices and Cyrix put constant pressure on Intel by rapidly producing devices which operated similarly to Intel's products. Competition in microprocessors kept the cost of the devices low and accelerated the rate of innovation.

The limited economies of scale and low entry barriers discouraged the development of dominant market leaders in the supply of printed circuit boards. In 1992, only 13 U.S. firms had revenue greater than \$50 million while more than 600 operated with sales of less than \$5 million.<sup>44</sup>

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44. The Institute for Interconnecting and Packaging Electronic Circuits (IPC). "TMRC Analysis of the Market, Rigid Printed Wiring Boards and Related Materials for the Year 1991," June 1993

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### Distinctive Environmental Regulation in the U.S.

Two areas of regulation affecting the manufacture of computers and electrical components in the 1990s were the releases of metals in printed circuit board manufacturing and controls on the use and release of solvents. In the U.S., industrial discharges to water bodies were regulated by the 1972 Federal Water Pollution Control Act (FWPCA) and the 1977 Clean Water Act (CWA). The FWPCA outlined a system of technology based standards for industrial effluent release. Under the legislation, the federal government was given the responsibility of determining the appropriate effluent limits within classes of producers. Permits were initially also issued by the federal government, but over time, most states took over responsibility for permitting. The 1977 CWA brought greater attention to toxic pollutants whereas the FWPCA had emphasized control of conventional pollutants (suspended solids and oxygen demanding organic releases).<sup>45</sup> Permits based on effluent standards resulting from the CWA put limits on the metals concentrations allowed in the releases from printed wiring board shops. The table below lists the allowable concentrations of metals in California (although local requirements often were more restrictive).<sup>46</sup>

Allowable Metals Concentrations in California Wastewater Releases		
Metal	Maximum for any one day	Average for four consecutive days
Cyanide	1.9 ppm	1.0 ppm
Copper	4.5 ppm	2.7 ppm
Nitrogen	4.1 ppm	2.6 ppm
Chromium	7.0 ppm	4.0 ppm
zinc	4.2 ppm	2.6 ppm
Lead	0.6 ppm	0.4 ppm
Cadmium	1.2 ppm	0.7 ppm

45. Portney, Paul R., Public Policies for Environmental Protection, Resources for the Future, Washington, D.C., 1990

46. As reported in "Selecting a Waste Treatment System that Works," \* James McCarron, Electronic Packaging & Production,

Achieving acceptable effluent levels required that PWB shops have wastewater treatment system. These could at times be extensive involving technologies such as ion exchange and plate-out equipment. Significantly, the regulations did not take into account the composition of the receiving waters or even the characteristics of the shops entry water. Producers at times claimed that the water which left their operations was substantially cleaner than that which had entered.<sup>47</sup>

As has been discussed, electronics manufacturing used large amounts of chlorofluorocarbons in the mid-80s. These chemicals were coming under increasing scrutiny because of their role in destroying stratospheric ozone. Beginning with the Vienna Convention for the Protection of the Ozone Layer, international organizations were taking actions to encourage national governments to take measures to protect the ozone layer. Taking effect on January 1, 1989, the Montreal Protocol established targets for CFC reductions (20% by mid-1993 and 50% by mid-1998). This measure was endorsed by 29 countries representing 83% of CFC consumption. Soon, however, increasing evidence was gathered indicating significantly greater damage to the ozone layer than had previously been measured. As a result, the London Revisions to the Montreal Protocol put more rapid targets in place for CFC reduction, 50% by 1995, 80% by 1997, and phase out by 2000. In December, 1991 there were 81 countries endorsing the London Revisions .<sup>48</sup>

The Clean Air Act Amendments of 1990 gave teeth to the commitments made by the U.S. to the Montreal Protocol. Title V of the Amendments established a phase out schedule which would eliminate the production and importation of CFCs, halons, and carbon tetrachloride by 2000. However, in February 1992, the Bush administration, responding to evidence of rapid destruction of the ozone layer, committed to accelerate the phase-out schedule from 2000 to 1995.<sup>49</sup>

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47. Rob Scott, CEO Phase II, Interview, September 16, 1993

48. Cummings, Christopher and Arnold, Matthew, "The Montreal Protocol Case," in The Greening of World Trade, U.S. EPA, February 1993

49. U.S. EPA, Report to the Office of Air and Radiation to Administrator William K. Reilly: Implementing the 1990 Clean Air Act: The First Two Years, November 15, 1992

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Although there were no regulations specifically addressing computer energy use in the U.S., the EPA had initiated a program which encouraged innovation in this area. Recognizing that energy efficiency in computer use provided a benefit to the user, the EPA set out to develop a voluntary program aimed at affecting buyer behavior. The agency established a set of guidelines which would qualify the computer to be affixed with an "Energy Star" label. The Energy Star designation provided quick identification for buyers that their purchase would meet a minimum level of energy efficiency. Additionally, all computers purchased by the federal government were required to meet the qualifications of the Energy Star program.

#### Characteristics of U.S. EPA Energy Star Program

##### Performance Requirements

- \* Computer or monitor must drop to a low power usage mode (less than 30 Watts) when inactive
- \* Printers must enter a low power mode of between 30 and 45 Watts (determined according to printer speed)

##### EPA Role

- I Provide recognition for participants
- \* Encourage public awareness of the economic and environmental benefits of energy efficient computers
- I Promote purchases of energy efficient computers
- I Promote government purchases of energy efficient computers

Source: U.S. EPA

### Sources of Competitive Advantage in U.S. Firms

#### *Factor Conditions*

Computers were manufactured using widely available materials and with a limited amount of assembly labor.<sup>50</sup> The key factor in innovation and upgrading in the industry was a supply of well trained technically sophisticated workers.<sup>51</sup> In the U.S., many schools offered graduate and undergraduate students programs which supported the computer industry. Notably, programs at the Massachusetts Institute of Technology, the California Institute of Technology, and Stanford University had built strong reputations for innovation and encouraged faculty and students alike to develop and market new technologies. The proximity to these universities offers some explanation for the clustering of computer firms on the Route 128 corridor in Massachusetts, and in the Silicon Valley in California.

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so. In 1991, U.S. computer and office equipment manufacturers incurred payroll expenses for production workers of only 3.9% of sales (compared to 9.4% average for all manufacturing industries).

5 1. Research and development costs in 1990 were 15.4 % of sales for computer and office equipment manufacturers and 8.6% of sales for electronic component producers. R&D for all industries averaged 3.2% (National Science Foundation data).

In addition to individuals who developed their skills through formal training, the computer industry (particularly in the 1970s and 1980s) seemed to offer a unique opportunity for bright young entrepreneurs who fell outside of traditional backgrounds. During following World War II and taking off after the 1960s the industry developed a subversive character which many in that period found attractive. The financial requirements were initially very low for innovative individuals to explore and develop new products. Because, there was no need to have access to large corporate or university laboratories, many of the most important developments in the industry came from small start-ups or even, as widely report& for Apple Computer, were achieved in the founder's garage.<sup>52</sup>

### *Domestic Demand Conditions*

The earliest stages of the development of the computer occurred because of the special needs of the military. During World War II, the military had recognized that advanced automated means were necessary to counter the rapidly advancing sophistication of enemies' encoding systems. After the conflict, the military identified other areas including guidance systems, air traffic control, and aircraft design which could benefit from improved computational methods. Funding flowed to university programs (dominated by the Whirlwind project at the Massachusetts Institute of Technology) and to private firms (initially to the Engineering Research Associates, a private firm started for the purpose of building on computer advances made during the war).<sup>53</sup>

Military demands also helped to fund the developments which would later lead to IBM's dominance of the commercial computer market. Advances which the company made while working on air defense and guidance programs for the government are credited with positioning IBM for its later introduction of the System 360 computer line.<sup>54</sup> In fact, between 1949 and 1959, government programs were responsible for 68% of IBM's research funding. The government share of research costs dropped through the 1960s

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52. See for example, Accidental Empires by Robert Cringely, Harper Business, New York, 1993

53. Flamm, Kenneth, Creating the Computer: Government, Industrv. and High Technology, The Brookings Institute, Washington, D.C., 1988

54. Flamm, Kenneth, Creating the Computer: Government, Industrv. and High Technology, The Brookings Institute, Washington, D.C., 1988

and 1970s.<sup>55</sup> However, given the high cost of developing the first computers, and the uncertainty of their eventual success, it is unlikely the later commercial market could have developed without the early government funding.

Participants in the early government programs were quick to recognize the opportunity for commercial applications of computer technology. In the U.S., this market surged in the 1960s encouraged by IBM's technical (standard platforms) and marketing (leasing contracts rather than direct sales) innovations. With the introduction of the personal computer, buyer sophistication concerning computer hardware reached a new level. For many computer buyers, gathering information on hardware crossed the border from a professional task to a hobby. Popular magazines provided information to these buyers offering critiques on computer performance, hints on software, and even gossip about the personal lives of industry leaders. A core of highly informed buyers pushed companies to provide ever faster, more powerful, and cheaper products.

U.S. electronic component manufacturers enjoyed large domestic demand in the early 1990s but manufacturers feared an erosion of their key markets. One measure indicated that the U.S. share of all electronic equipment had slipped from 41% in 1986 to 29% in 1992.<sup>56</sup> Although the electronics industry was considered among the most global of any manufacturing area, a loss of domestic markets could be devastating for upstream suppliers. The Semiconductor Industry Association estimated that in 1991, U.S. semiconductor manufacturers supplied 70% of the domestic market while their share of the overall world market was only 39% (as will be discussed later, Japan was in a similar position with 86% of home market and 47% of the world market).<sup>57</sup>

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55. Flamm, Kenneth, Targeting the Computer: Government Support and International Competition, The Brookings Institute, Washington, D.C., 1987

56. USITC, Industry & Trade Summary: Semiconductors (USITC publication 2708) December, 1993

57. Howell, Thomas R., et.al., Creating Advantage: Semiconductors and Government Industrial Policy in the 1990, Semiconductor Industry Association, 1992

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The U.S. market for printed wiring boards was also strong in the early 1990s, although here also manufacturers were concerned over loss of their markets as a result of their customers moving production to low wage developing countries. In 1992, 28.9% of the world PWB market was in the U.S.<sup>58</sup>

The U.S. demand for semiconductors and PWBs was smaller than that in Japan, causing concern for many industry analyst. However, the U.S. demand for these products had a higher portion of computer, military, and telecommunications applications. The Japanese markets were dominated by consumer electronics applications. In many cases, the design aspects of the U.S. markets led those of the Japanese markets (while those demanded by the Japanese markets typically led production developments). Responding to these differences, the U.S. share in some subsegments of the market were dominant (while the Japanese share was similarly dominant in others). For example, the requirements in the U.S. for two sided and multi-layer epoxy/glass PWBs led to technical advances in this area by domestic suppliers. Japanese demand, on the other hand, had a higher weight of 1-sided boards based on a paper substrate. In semiconductors, despite the often cited loss of the memory chip market, the U.S. had remained the leading supplier of microprocessors and application specific integrated circuits, components associated with areas where the U.S. led in the end-product.

#### *Related and Supporting Industries*

The strength of the U.S. computer industry was inescapably linked to the health of the nation's semiconductor manufacturers. Computer firms counted on new software developments to encourage customers to buy new upgraded systems. The software, in turn, required advances in microprocessors to allow expanded and quickly functioning features. As the leading developer of microprocessors, Intel Corp. had a great deal of leverage over the industry. The early 1990s had been particularly successful for the company as it achieved after tax return on sales of 17-18% from 1990 through 1992, and an astounding 26% in 1993.<sup>59</sup>

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58. The Institute for Interconnecting and Packaging Electronic Circuits, "TMRC Report on the World Market for Printed Wiring Boards and Substrate Materials for 1992," Chicago, 11, June 1993

59. Intel Corporation, 1992 Annual Report

U.S. firms were in a much less desirable position in a second critical supporting industry. In memory chips, the U.S. had suffered devastating losses in market share during the 1980s. A concerted effort by Japanese manufacturers (discussed below) which included cooperative research among firms, government funding of research, and less than fair market pricing in the U.S., had driven the U.S. share of the DRAM chip market from greater than 70% in 1978 to less than 20% in 1986. As a result, many U.S. computer firms relied on Japanese companies for DRAM chips.

Semiconductor firms also relied on related and supporting industries. Here, also, the coordinated efforts of the Japanese government and industry in the early 1980s had eroded a previously dominant U.S. position. Photolithographic imaging equipment was a critical area of technology in semiconductor manufacturing. In 1982, the U.S. share of the market for this equipment was 58%; by 1989, the U.S. share had diminished to 18 % . Two Japanese firms, Nikon and Canon, supported by government research projects, had taken over market shares of 38% and 24% by introducing equipment advances. On the other hand, U.S. firms continued to lead in chemical deposition and ion implantation equipment.<sup>60</sup>

U.S. firms held only 17 % of the market for semiconductor materials in 1989. In many cases, the U.S. position had been eroded because companies were sold to Japanese or European manufacturers, and many firms continued to produce semiconductor materials in the U.S. Although these firms continued some manufacturing in the U.S., in some areas there had been an almost complete elimination of U.S. ownership of operations. In silicon wafer production and in ceramic packages, the U.S. position was negligible.<sup>61</sup>

Critical supplies for the printed wiring board industry included glass/epoxy prepreg and dry film photoresist. U.S. suppliers of these materials led technical developments. In particular, DuPont, the

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60. USITC, Global Competitiveness of U.S. Advanced-Technology Manufacturing Industries: Semiconductor Manufacturing and Testing Equipment: Report to the Committee on Finance, United States Senate (investigation No. 332-303 (final)), USITC publication 2434, September 1991

61. USITC, Global Competitiveness of U.S. Advanced-Technology Manufacturing Industries: Semiconductor Manufacturing and Testing Equipment: Report to the Committee on Finance, United States Senate (investigation No. 332-303 (final)), USITC publication 2434, September 1991

leading supplier of photoresist led such technical efforts as the development of aqueous soluble photoresist materials.

### *Strategy, Structure, and Rivalry*

Three factors combined to make the U.S. computer and electronic components markets highly competitive: in the early stages of each of these industries, the key technologies were made available to the public at large, a single individual could provide the critical technical insights needed by a new entrant to the market, and a sophisticated market of venture capital investors had developed to support new firms.

The earliest computer designs were funded by the government and completed in the academic environments of Princeton and MIT. This had a profound effect on the accessibility of early innovations. For example, one of the first computer projects was led by John Von Neumann at Princeton. Reports of the project's progress and technical insights were published by team members and, thus, made available to all potential entrants in the early computer industry.<sup>62</sup> The free exchange of technical information remained a characteristic of the industry until large commercial markets became evident.

The pioneers of the computer industry often did not remain patient with their early organizations. In the 1960s, Ken Olsen gathered experience with IBM prior to starting DEC. Similarly, Gene Amdahl had led the design of early IBM computers prior to starting his own firm. Defections of key technical personnel had been a characteristic of the industry even at its inception. William Norris, one of the earliest computer designers, left Sperry Rand to found the Control Data Corporation (CDC). Later Seymour Cray left CDC to found Cray Research. Both of these firms were located in Minneapolis, Minnesota where a cluster of computer firms had developed, many of which could be traced back to the early founding of the Engineering Research Associates firm there in 1945.

Much like the first computer designs, the earliest insights in transistors were rapidly introduced to the public domain. Also paralleling the computer industry, the U.S. semiconductor industry grew as key technologists in one firm left to begin their own operations. The first transistors were developed in the

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62. Flamm, Kenneth, Creating the Computer: Government, Industry, and High Technology, The Brookings Institute, Washington, D.C., 1988

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Bell Telephone laboratories in 1948. William Shockley later won the Nobel prize for his innovative development of the “bipolar” transistor which allowed current flowing in one direction to control the flow of current along a second path. As required by earlier antitrust settlements, Bell made the technology widely available. Shockley, himself, took advantage of the free use of the innovation and initiated his own firm in 1955. In turn, several scientists left Shockley Semiconductor Laboratories to form Fairchild Semiconductor from which Gordon Moore and Robert Noyce departed in 1968 to begin Intel.<sup>63</sup> Later entrepreneurs would leave Intel to start still other firms.

### *The Role of Government*

There is perhaps no other industry in which the role of government was more important than that of electrical devices and electronic components. U.S. government agencies, particularly the Department of Defense and the Bureau of Census were the first organizations to recognize potential applications for the computer. Government funding for academic and commercial development was crucial to the industry's early growth. However, the U.S. government's role in shaping the electronics sector went well beyond that which it played as a leading buyer.

In the 1960s, Japanese manufacturers had overtaken U.S. firms and gained dominating share of world markets for televisions and other consumer electronic devices. In the 1980s manufacturers of computers and electronic components used this experience to gain the attention of policy makers. A similar loss of production capacity for computers and semiconductors, they argued, would damage all downstream users of these products and, further, endanger national defense because of the role of these products in many of the devices used in modern warfare.

A series of International Trade Commission investigations conducted throughout the 1980s found that Japanese manufacturers were selling semiconductors at well below the cost of production. By protecting home markets and aggressively pricing in foreign markets, the Japanese manufacturers, it appeared, were attempting to take advantage of the scale and learning curve advantages which could be gained by rapidly

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63. Zaks, Rodney, From Chips to Svstems: An Introduction to Microprocessors, Sybex, Berkeley, 1981

achieving large market share positions. U.S. firms, unable to sustain the large losses necessary to combat the Japanese pricing, quickly exited the market.

By 1986, the U.S. share of the worldwide DRAM market had plummeted to a point below 20 % . Semiconductor manufacturers in other segments such as EPROMs (electrically programmable read only memory), SRAMs (static random access memory), and ASICS (application specific integrated circuits) feared that without a response to the Japanese practices, these markets would be similarly lost. U.S. manufacturers were dissatisfied with the response of the Japanese government to an early 1980s pact, The High Tech Working Group Agreement, and encouraged the U.S. government to achieve more substantial action.<sup>64</sup>

In 1986, the two governments set a new framework in the US-Japan Semiconductor Trade Arrangement. In a side letter (initially a confidential document among the negotiators but later made public), the Japanese government agreed to encourage manufacturers to use more non-Japanese semiconductors. A goal of 20% of the Japanese market was recognized. Despite the Japanese commitments, U.S. firms saw a reduction in their share of the Japanese market in the year following the agreement. In response to the apparent lack of efforts, the U.S. government imposed trade sanctions on a variety of Japanese consumer electronics. Soon after, Japanese electronics companies began to work more closely with U.S. firms to incorporate U.S. semiconductors in their products. Additionally, pricing for Japanese semiconductors in the U.S. were returned to a more competitive level .<sup>65</sup>

The opening of the Japanese market is estimated to have yielded more than \$1 billion in incremental revenue to U.S. firms. However, the agreement also provided an opportunity for Japanese firms to take advantage of the dominant position they had established in the DRAM market. Several authors have concluded that the rapid run up in DRAM prices which occurred in the late 1980s can be linked directly

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64. Howell, Thomas R., et.al., Creating Advantage: Semiconductors and Government Industrial Policy in the 1990, Semiconductor Industry Association, 1992

65 Howell, Thomas R., et.al., Creating Advantage: Semiconductors and Government Industrial Policy in the 1990&, Semiconductor Industry Association, 1992

to MITI establishment of production and export guideposts.<sup>66</sup> Between the first quarter of 1986 and the second quarter of 1989, prices for 256K DRAMS increased by more than 50%.<sup>67</sup> The benefits accrued primarily to the leading Japanese semiconductor firms, but they can also be seen in the results for Micron Technology, one of the two remaining U.S. DRAM producers. In 1988 and 1989, the company enjoyed after tax returns of 33% and 24% after having suffered losses in 1986 and 1987.<sup>68</sup> Although the Semiconductor Trade Agreement has been blamed for allowing the “cartelization” of the DRAM market, it has also been credited with stemming the U.S. loss of position in other segments of the semiconductor market such as EPROMs and with increasing the U.S. share of the Japanese market.

The U.S. government also played a role in the semiconductor industry by encouraging means for coordinated research and development. Basic research, assumed to be of value to all industry participants, was conducted without fear of antitrust actions by organizations such as the Microelectronics and Computer Technology Corporation (MCC) and the Semiconductor Research Corporation. In the case of SEMATECH, a research consortium aimed at advancements in semiconductor manufacturing technology, the federal government provided approximately half of the organizations \$200 million in 1992 funding.<sup>69</sup>

## Japan

### Competitiveness Overview

Japan ranked second behind the U.S. in computer production with a 30% share of the world market in 1992 (having improved on a 26% share held in 1988).<sup>70</sup> Japanese firms provided equipment in the supercomputer, mainframe, and personal computer segments, but in the early 1990s, no Japanese

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66. See for example, Tyson, Laura D’Andrea, “Managing Trade and Competition in the Semiconductor Industry” in Who’s Bashing Whom?, Institute for International Economics, Washington, D.C., 1992

67. Data from Dataquest presented in Tyson, Laura D’Andrea, “Managing Trade and Competition in the Semiconductor Industry” in Who’s Bashing Whom?, Institute for International Economics, Washington, D.C., 1992

68. Micron Technology, company financial information

69. SEMATECH, 1992 Annual Report

70. U.S. International Trade Commission, “Global Competitiveness of U.S. Advanced-Technology Industries: Computers,” Investigation No. 332-339, December 1993

company had achieved a significant position in workstations. Supplying primarily domestic demand, Japan held a fairly low share of world exports of computers. In 1990, Japan is reported to have supplied only 10% of internationally traded computers and central processors.<sup>71</sup>

### Leading Firms

In contrast to developments in the U.S., the Japanese computer industry was dominated by firms which had been in existence long before the invention of the transistor. Several firms, including NEC and Fujitsu, had provided equipment to the nation's telecommunications industry while others such as Toshiba had been involved in the production of electrical equipment (Hitachi had been in both markets).<sup>72</sup>

Fujitsu was the largest Japanese manufacturer of high end computer products ranking as the world's second leading producer of supercomputers (behind Cray Research of the U.S.) and the second leading producer of mainframes (behind IBM of the U.S.). In both cases, Fujitsu was estimated to have approximately 40% of the revenue of the leading firms.<sup>73</sup> NEC was Japan's largest producer of personal computers. Supported by a 53% share of the home market, NEC ranked behind only IBM in share of world personal computer production.<sup>74</sup>

Although computer and electronic component manufacturing had become critical in firms which also supplied electrical equipment, in several leading firms, it remained one (important) division of a larger diversified organization. Information systems and electronics provided 38% of Hitachi's 1993 revenue for example while power and industrial systems, consumer products, and materials provided the remainder.<sup>75</sup> Toshiba similarly received 49% of 1993 revenue from information systems and electronic

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71. United Nations, "UN Trade Statistics Yearbook, 1990"

72. Fransman, Martin, The Market and Beyond: Cooperation and Competition in Information Technology Development in the Japanese System, Cambridge University Press, Cambridge, 1990

73. U.S. International Trade Commission, "Global Competitiveness of U.S. Advanced-Technology Industries: Computers," Investigation No. 332-339, December 1993

74. Schlender, Brenton, U.S. PCs Invade Japan, *Fortune*, July 12, 1993

75. Hitachi Ltd., 1993 Annual Report, Year ended March 31, 1993

devices with the rest derived from heavy electrical apparatus and consumer products activities.<sup>76</sup> In other firms such as NEC and Fujitsu, computer and communications operations and the supporting components production dominated the firm's revenue.

Major Japanese computer firms were highly vertically integrated and the same large firms which led Japanese computer production also led in semiconductor sales. NEC had been the world's largest semiconductor manufacturer throughout the late 1980s, but the company had moved to the second position behind Intel in 1993. As has been noted, Japanese firms held a commanding share of the world memory chip market and were very strong in such areas as application specific integrated circuits. Behind NEC's 1993 semiconductor sales of \$6.4 billion were Toshiba, Hitachi, and Fujitsu at \$5.8 billion, \$4.7 billion, and \$3.3 billion respectively.<sup>77</sup>

Even in printed wiring boards, Japanese production was dominated by large firms. In 1991, only 31% of the Japanese production was supplied by firms with less than 300 employees. Further, these small and mid-sized firms were losing share as in 1990, these suppliers had provided 43 % of Japanese production.<sup>78</sup>

### **Distinctive Environmental Regulation in Japan**

Japanese electronics manufacturers faced environmental regulations very similar to those in the U.S. Here, water pollution was controlled through a set of effluent guidelines established through national legislation and air releases (of CFCs) were regulated as a result of the nation's participation in the Montreal Protocol.

Environmental issues were thrust into the Japanese national consciousness with the outbreak of "Minamata disease" in 1956. Damaging the central nervous system, this disease resulted from the release of methyl-mercury byproducts from Chisso Hiryo Co.'s production of acetaldehyde in Minamata City. The chemical had bioaccumulated in fish which were subsequently eaten by the local population. Ultimately

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76. Toshiba Corporation, 1993 Annual Report, Year ended March 31, 1993

77. VLSI Research Inc., Press Advisory, "1993 Top Ten Semiconductor Companies," November 23, 1993

78. "Printed Circuit Boards," in Japan Electronics Almanac '93/'94, Dempa Publications, Inc., Tokyo/New York, 1993

affecting more than 5000 people, the emergence of this ailment led the Japanese government to begin to control the environmental effects of the country's growing industrial complex.<sup>79</sup> In 1958, the central government passed two measures, one regulating effluent releases from industry, and the other addressing water conservation. However, these early measures were thought to be limited in scope and lacked strong enforcement. Only in the 1970s did the Japanese government begin to regulate on a national level in a way that significantly affected industry's effluent releases.

Allowable Metals Concentration in Japanese Wastewater	
Metal	Concentration
Cadmium	0.1 mg/l
Cyanide Compounds	1 mg/l
Lead	1 mg/l
Hexivalent Chromium	0.5 mg/l
Copper	3 mg/l
Chromium	2 mg/l

Source: Japan Environment Agency

Effluent standards were set in the Water Pollution Control Law of 1970 establishing permissible limits for eight parameters. Prefecture governments could establish more strict criteria if the local needs warranted. Other parameters such as polychlorinated biphenol were added as their impact on human health were determined. Then, in 1993, responding to revised drinking water guidelines from the World Health Organization, the Japanese government expanded the list of substances to 23.<sup>80</sup> The permissible limits on several metals important to the printed wiring board industry are included in the attached table.<sup>81</sup>

Japan passed the "Law Concerning the Protection of the Ozone Layer through the Control of Specified Substances and Other Measures" (known as the Ozone Layer Protection Law) in May of 1988. This law established the methods by which Japan would follow through on the commitments it made by

79) Environment Agency, Government of Japan, "Quality of the Environment in Japan, 1992"

80. Environment Agency, Government of Japan, "Water Pollution Control Administration"

81. These values are reported in mg/l as they were provided in the source document ("Water Pollution Control Administration"). Taking a liter of water as 1 kilogram, 1 mg/l would be equivalent to 1 ppm. Given this, the Japanese limits on cyanide and copper are roughly similar to the "average of four monitoring days" limits reported for California above. Japan's limits on cadmium and chromium are more strict while California requires significantly lower lead content.

participating in the Montreal Protocol. As in other participating countries, Japanese businesses were required to phase out the use of CFCs and carbon tetrachloride by 2000 and trichloroethane by 2005.<sup>82</sup>

## **Sources of Competitive Advantage in Japan**

### *Factor Conditions*

As has been stated, electronics manufacturing was not dependent on traditional types of factor endowments. Materials made up a minimal part of the overall value of the devices and most of those that were used were widely available. Japan's electronics industry was supported by a highly specialized workforce. Tokyo University, Tohoku University, and Kyoto University all participated in the early development of the computer industry in Japan. In most cases, these institutions worked closely with industrial partners so advances made in the academic environment were rapidly transferred to the commercial arena. Students participating in these programs were among the best in the nation. MITI had targeted a strong computer industry as critical to the nation's health. This sort of targeting had a profound effect on the professional choices of students. Targeted industries represented status, and the helpful guidance of MITI increased the odds that the computer industry would provide greater opportunities for growth than other, integrated areas. Finally, when the government and industrial efforts began to pay off, companies such as NEC and Fujitsu began to look like very secure environments in which to dedicate one's lifetime employment efforts. All of these factors helped the computer industry to attract a committed highly capable workforce.

### *Domestic Demand Conditions*

The Japanese demand for computers was not unusually large or sophisticated in any way which would lead demand in other nations. It was, however, critically important to the health of Japanese computer makers. As in other targeted industries, government programs were established in the computer market which benefited manufacturers while imposing higher costs on buyers. By imposing higher tariff rates on computers in the early 1960s, the Japanese government intended to foster the embryonic industry. Encouraged by this and other government actions (discussed below), Japanese manufacturers set out to

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82. Environment Agency, Government of Japan, "Quality of the Environment in Japan, 1992"

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match the technical performance of the leading U.S. performers. By 1966, Japanese firms had claimed more than 50 % of the home market .<sup>83</sup>

Japanese demand for computers was primarily driven by industrial needs. Unlike the government and defense buyers in the U.S., Japanese industrial buyers were not often willing to finance the very high expenditures incurred in developing leading edge computer technologies. Therefore, Japanese manufacturers followed closely U.S. innovations, incorporated them into their designs, and then provided them to their protected markets.

In the personal computer market of the early 1990s, an additional characteristic of Japanese demand further protected the market but also limited its size. Japanese writing, kanji, incorporates thousands of characters making keyboard input extremely difficult. Partially for this reason, personal computer penetration was only 115 per 1000 people in Japan in 1993 (as compared to 308 in the U.S.).<sup>84</sup> The difficulty in supporting a kanji system delayed U.S. firms' entry in the Japanese market. However, developments associated with adapting to kanji provided few benefits to Japanese producers which were transferable to other markets.

For semiconductor manufacturers, the home demand was instrumental in driving the strong Japanese competitive position. Initially, the industry was fostered by procurement contracts from Japan's large telecommunications company, Nippon Telephone and Telegraph (NTT). Contracts with NTT in Japan paralleled closely those by the DOD in the U.S. NTT demanded leading edge technology and subsidized its development. The company also worked closely with its suppliers as products were prepared. A significant share of these benefits were enjoyed by NTT's family of primary suppliers including NEC, Fujitsu, and Oki. Some analysts have suggested that later advantages for Japanese firms in high volume

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83 Fransman, Martin, The Market and Beyond: Cooperation and Competition in Information Technology Development in the Japanese System, Cambridge University Press, Cambridge, 1990

84 Schlender, Brenton, "U.S. PCs Invade Japan," *Fortune*, July 12, 1993

semiconductors owes substantially to NTT's early needs while the U.S. emphasis on design can be traced to the demands of the U.S. DOD.<sup>85</sup>

A second area of strong home demand for the Japanese semiconductor industry was in consumer electronics. Japanese production of consumer products was more than ten times that of the U.S. in the early 1990s.<sup>86</sup> As much as 30 % of the Japanese market for semiconductors was driven by this sector. Here again, the demand emphasized low cost and mass production rather than advanced design.

#### *Related and Supporting Industries*

The Japanese computer and electronic devices industries were supported by the nation's strong position in semiconductors. This in turn, synergistically supported and was supported by a strong semiconductor equipment industry. Japanese growth in semiconductors spurred a concurrent development of a domestic semiconductor equipment industry. Between 1979 and 1983, home demand was credited for the growth in share of world markets for Japanese suppliers from 15 % to 25 % in wafer processing, and 7 % to 21 % in test equipment.<sup>87</sup> The growth of the semiconductor equipment industry continued to be tightly tied to that of semiconductors throughout the 1980s. In 1989, 76% of Japanese demand for semiconductor equipment was satisfied by domestic suppliers.<sup>88</sup>

Worldwide, the Japanese share of semiconductor equipment had risen from 18% in 1980 to 39 % in 1988.<sup>89</sup> This had been driven by three factors, the dominant home market position described above, selective acquisitions by Japanese firms of U.S. suppliers, and technical innovations by Japanese

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85 Howell, Thomas R. et. al., The Microelectronics Race: The Impact of Government Policy on International Competition, Westview Press, Boulder, 1988

86. McKinsey and Company, "Productivity in the Consumer Electronics Industry," in *Manufacturing Productivity*, McKinsey Global Institute, Washington, D.C., October, 1993

87. U.S. Department of Commerce, "A Competitive Assessment of the U.S. Semiconductor Manufacturing Equipment Industry, Washington, D.C., 1985

88. USITC, *Global Competitiveness of U.S. Advanced-Technology Manufacturing Industries: Semiconductor Manufacturing and Testing Equipment: Report to the Committee on Finance*. United States Senate (investigation No. 332-303 (final)). USITC publication 2434, September 1991

89. U.S. Department of Commerce Bureau of Export Administration, "National Security Assessment of the U.S. Semiconductor Wafer Processing Equipment Industry, " April, 1991

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companies (at times achieved through government programs). Technical leadership, of course, reinforced the home market position of Japanese suppliers, but where technologies were equal (or near equal), Japanese manufacturers tended to purchase domestically. High levels of vertical integration encouraged this behavior as, for example, Hitachi grew to become one of the world's ten largest semiconductor equipment suppliers. Technical leadership was most evident in the area of photolithography. In the mid-80s, Nikon overtook Perkin Elmer and GCA Corp. when it introduced a stepper which far surpassed earlier technologies.<sup>90</sup>

### *Strategy, Structure, and Rivalry*

Although U.S. observers often saw Japanese manufacturers as a unified competitive force, this view underestimates the fierce domestic competition existing for the home market. Patient capital markets and traditions of lifetime employment drove an emphasis on market share rather than near term profitability by Japanese producers in many industries. This was especially evident in electronics and semiconductors. In fact, this approach explains the distinctly different strategies by U.S. and Japanese manufacturers in the 1980s.

Japanese manufacturers were protected in their home markets for both computers and semiconductors. Domestic firms competed along traditional lines of price, performance, technical leadership, and service. However, manufacturers recognized the large learning and scale benefits in these industries and struggled to achieve high production levels. Foreign markets (especially in the U.S.) were targeted to provide greater scale and more rapid learning.

Whereas U.S. firms approached the market with a traditional desire to achieve returns for current capital investment (and fund technical efforts), Japanese firms were in a race to most rapidly acquire production learning and in turn build market share. The differing goals led to diametrically opposed responses to a reduced demand for semiconductors in 1985. While U.S. firms attempted to remain profitable through production cut backs and reductions in spending on research and development, Japanese firms kept production high and flooded the U.S. market with chips which were priced well below their cost of

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90 U.S. Department of Commerce Bureau of Export Administration, "National Security Assessment of the U.S. Semiconductor Wafer Processing Equipment Industry," April, 1991

production. This strategy was only made possible because Japanese manufacturers were part of larger companies which could support losses in semiconductor divisions through the financial strength of other areas.

As a whole, the Japanese approach resulted in the rapid departure of U.S. firms from the targeted segments of the semiconductor industry. Collectively, Japanese firms achieved their goal of dominant market share. However, multiple large Japanese suppliers (six with sales in excessive \$2.4 billion in 1993) continued to compete.

### *The Role of Government*

While the U.S. government's role in the computer and electronic component industry was typically reaction oriented, the Japanese government, through MITI and other agencies, was an active participant in the development of the nation's industry. Government actions in Japan included, protecting the domestic market from foreign products through high tariffs, the establishment of organizations which would foster domestic demand, and the subsidization and coordination of research.

Japanese tariff rates for computers and semiconductors remained above 10% through the 1960s and 1970s.<sup>91</sup> In addition rigid import controls allowed MITI to further limit the number of items which were brought in even with these tariffs. In the 1980s, after a home industry had been established, the Japanese rates were brought into parity with other computer producing countries.<sup>92</sup>

The Japanese government also fostered the development of the young industry through the establishment of the Japanese Electronic Computer Corporation (JECC). This organization, subsidized by the Japan

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91. Flamm, Kenneth, Targeting the Computer: Government Support and International Competition, The Brookings Institute, Washington, D .C., 1987

92. U.S. International Trade Commission, "Global Competitiveness of U.S. Advanced-Technology industries: Computers," Investigation No. 332-339, December 1993

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Development Bank, provided low interest financing for the purchase of Japanese built computers. Strict “domestic content” rules made the influence of JECC felt far up the supply chain for electronic devices.<sup>93</sup>

The Japanese government encouraged technology development through its laboratories in MITI and Nippon Telephone and Telegraph (NTT). Firms which were later to lead the Japanese computer and electronics industry such as Fujitsu and NEC took their first steps into the market using developments from these laboratories.<sup>94</sup> Later, the Japanese government’s role incorporated fostering and coordination along with direct subsidization. In particular, in the VLSI research project of 1976-1980, MITI coordinated the research efforts of five leading electronics firms into six laboratories exploring basic developments of semiconductor manufacturing.<sup>95</sup>

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93. Flamm, Kenneth, Targeting the Computer: Government Support and International Competition, The Brookings Institute, Washington, D.C., 1987

94 Fransman, Martin, The Market and Beyond: Cooperation and Competition in Information Technology Development in the Japanese System, Cambridge University Press, Cambridge, 1990

95. Fransman, Martin, The Market and Beyond: Cooperation and Competition in Information Technology Development in the Japanese System, Cambridge University Press, Cambridge, 1990

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## EFFECTS OF REGULATION ON COMPETITIVE ADVANTAGE

### Direct Effect on Product

Energy used to power an idle computer was truly a wasted resource. That energy use represented costs to the computer's user and its production contributed to environmental problems such as global warming and acid rain. Despite these facts, computer users did not become aware of the potential benefits of more energy efficient computers until the early 1990s. At that time, the U.S. EPA developed a program under which computers which met minimum standards of energy efficiency would be labeled with a sticker (using an "Energy Star" logo). Using technology developed for laptop computers, most manufacturers were quickly able to provide systems which easily met the programs requirements.

The Energy Star program was given a strong boost in 1993 when the Clinton administration issued an executive order stipulating that all computers purchased by the federal government meet Energy Star requirements. Inspired by those stated intentions of the world's largest purchaser of computers, manufacturers rapidly provided compliant systems. In October of 1993, the U.S. EPA reported that manufacturers representing approximately 70% of U.S. computer sales had developed computers which met the requirements.<sup>96</sup> While the government's purchase decision had an important accelerating effect on the Energy Star program, manufacturers anticipated that other markets would rapidly develop. Among the 136 firms producing energy efficient computers in late 1993 were the Japanese firms NEC and Toshiba, companies unlikely to anticipate sales to the U.S. government.<sup>97</sup>

The development of energy efficient computers represented a win-win for the computer suppliers and their customers. For the buyers, energy efficiency was provided without additional costs. Thus, a 50-75 % savings in the operating cost of the system could be acquired at no expense. Although the operating cost of a computer was often overlooked by buyers, it could represent a significant share of the life cycle cost

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96. U.S. EPA, Information Flier, "EPA Energy Star Computers," October 14, 1993

97. Japanese firms were not developing energy efficient computers merely for the U.S. market. In the early 1990s most Japanese electronics manufacturers had established energy use reduction targets for their products. Hitachi, Fujitsu, and NEC explicitly targeted production of more energy efficient products in their environmental plans.

of the computer. Buyers of Energy Star computers could potentially save \$75 annually on a system which had capital costs of \$1500.

Computer suppliers were able to provide energy efficiency at no additional costs and without having to incur large R&D expenses (much of the technology was simply transferred from laptop computers). For the existing base of computers, a company called PC Green Technologies, Inc., had introduced an external device which would put computers and peripherals into a sleep mode when not being used. The product was being sold for \$89.95 and reportedly could yield \$100 annually in energy savings.<sup>98</sup> Manufacturers benefited from the improved image supplying energy efficient devices could provide. Capitalizing on this some manufacturers extended the Energy Star concept to develop “Green PCs” which utilized increased recycled material, were designed for ease of disassembly for future recycling, and were shipped in ways that minimized packaging.

### **Direct Effects on Production Process**

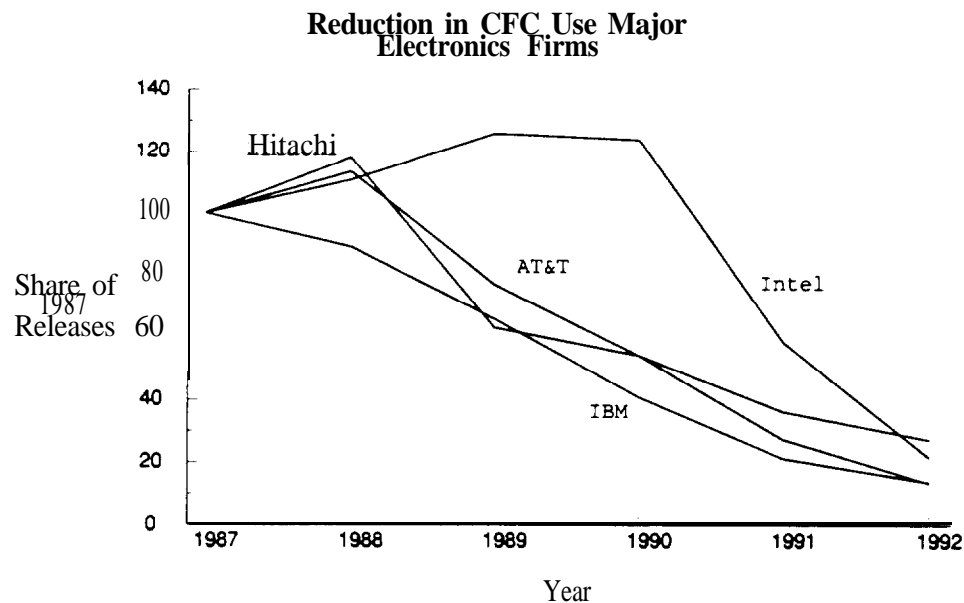
Environmental concerns affected the computer production process in a number of ways. Notably, the elimination of CFCs from the manufacturing process and the requirement for controlling discharge from plating operations (in PWB production) dramatically influenced the materials and processes used in making computer and electronic components. In some cases, companies supplying materials to computers and device manufacturers saw entire markets disappear and others appear as a result of environmental initiatives. In a few instances, responding to environmental challenges affected the competitive position and strategies of the companies themselves.

Analysts were initially very concerned about the effect of the Montreal Protocol on the electronics industry. It was feared that if all countries did not join in the effort to eliminate the use of CFCs, those countries which did would see electronics manufacturing operations move to those which did not. Given these early worries, the ability of the industry to remove the substances from their production in less than a decade provides an impressive example of how industry can innovatively respond to a compelling (and legally addressed) environmental problem.

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98 “Computer Users Save \$ and Power with New Gizmo,” PC technologies, Inc., Company Press Release, Feb. 1, 1994

Many electronics manufacturers achieved the goals of the Montreal Protocol well in advance of the initiative's schedule. Large firms from around the world such as AT&T, Hitachi, IBM, and Intel (and many others) made public commitments to achieve CFC free production in the years 1993-1995. Information provided by these companies typically showed 30-50% reductions in CFC use in the late 1980s. Much of these reductions resulted from simple house-cleaning types of efforts. Storage vessels were covered, solvent was recycled, and awareness programs were implemented.<sup>99</sup>



Note: IBM data are for CFC-113 only; Intel data include all ozone depleting substances  
Source: Company Environmental Reports

99. See for example, Patell, James and Marcy Trent, "AT&T Environment and Safety," The Management Institute for Environment and Business, Washington, D.C., 1993 or Fujitsu Company, "CFC-113 Replacement by Aqueous Cleaning Systems," Ichiro Yoshida, Fujitsu Limited

### Cost Saving Pollution Prevention Programs For Eliminating CFCs From Electronic Manufacturing

Source	Project	Capital Investment	Annual Return	Payback Period
ICOLP	AT&T use of terpene immersion cleaning of printed circuit boards replacing CFC process		28% reduction in operating costs	
ICOLP	Motorola implementation of terpene cleaning of printed wiring boards		81% reduction in operating costs	
EPA/SEDUE/ CANACINTR A	Addition of recycling and engineering controls to electronics cleaning	\$11,000	\$5,248 annual operating savings	
AT&T	Substitution of "no clean" solder flux for material which previously required perchloroethylene cleaning			Less than 12 months
Defense Contractor	Replacement of PWB cleaning with terpene process (per line of 500 boards/day)	\$37,000	\$18,000 annual operating savings	
Fujitsu	Shift from solvent cleaning and degreasing of PWBs to mechanical and aqueous methods in one facility	\$106,000,000	\$660,000 annual operating savings	

Many of the steps taken in the first phase of CFC reduction addressed areas where material was being wasted. Reducing the amount of solvent which evaporated or was replaced prematurely allowed plants to continue production while using significantly lower volumes of CFCs. Elimination of the materials was a very different undertaking. Manufacturers targeting CFC-free production had to examine every area where CFCs were used and either develop processes where these steps were removed or identify suitable substitutes which performed the function previously achieved by the CFCs.

As the concerns about destruction of the ozone layer developed, the prospect of eliminating all CFCs from electronics production had initially seemed a formidable challenge. Companies first responded to calls for CFC elimination by pointing out that the link between the chemicals and the measurements of the ozone hole remained ambiguous and certainly did not justify the enormous costs to be borne by business if CFCs were to be phased out. Many factors contributed to the industry's change in posture,

but David Chittick, Vice President for Environment and Safety for AT&T, has suggested that three were pivotal :<sup>100</sup>

- 1) One manufacturer's development of a process for using a cost competitive, biodegradable solvent as a replacement for CFCs in flux removal processes.<sup>101</sup>
- 2) Northern Telecom, a large telecommunications company took the lead by committing to eliminate CFCs from manufacturing by the end of 1992. Once one firm had announced that CFC elimination was possible, others followed.
- 3) The United Nations Environmental Programme (UNEP) formally concluded that all areas of CFC use could be eliminated if existing technologies were readily transferred.

Encouraged by the Global Change Division of the U.S. EPA, the electronics industry began to support the possibility of eliminating CFCs within, or even ahead of, the Montreal Protocol schedule. In September of 1989, executives from AT&T and Northern Telecom working with the U.S. EPA invited representatives from fifteen other electronics firms to join a cooperative effort to find methods of reducing CFC use. Later named the Industry Cooperative for Ozone Layer Protection (ICOLP), the organization offered a means of providing and acquiring information on new technologies.<sup>102</sup> ICOLP was a truly international undertaking with the initiating North American firms being joined by such Japanese companies as Hitachi, Matsushita, and Toshiba, and recognizing as affiliate members such organizations as the Russian Institute of Applied Chemistry and the Korea Anti-Pollution Movement.

The primary goal of ICOLP was information exchange. The organization provided information in the form of workbooks suggesting means of reducing and replacing CFCs in the manufacture of electronic components. Also, ICOLP established a internationally accessible database called OZONET. The database, which could be accessed for free through a variety of EPA, United Nations, and corporate

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100. Chittick, David, "The Transfer of Non-chlorofluorocarbon Technologies: A Case-Study in Industry Cooperation," Advanced Technology Assessment System Bulletin, Spring, 1992

101. The chemical used was a terpene solvent extracted from oranges. Other manufacturers later employed terpenes derived from cantaloupes, lemons, and other natural sources.

102. Long, Fredrick and Arnold, Matthew, The Power of Environmental Partnerships, Dryden Press, 1994

systems provided similar information. Finally, ICOLP representatives led workshops and demonstration projects in developing countries.<sup>103</sup>

Although some capital expenditure was required to implement many of the technologies suggested by ICOLP, the payback period for such investment was surprisingly short: often less than one year.<sup>104</sup> The benefits came from significantly lower chemical Costs, reduced waste disposal costs, or process savings from eliminating production steps. In several cases, manufacturers realized that cleaning steps used in production were not required either for performance or appearance reasons. More often, alternative cleaners were employed. Vendors of substitute cleaners had quickly recognized the opportunities available for successful CFC replacement materials. ICOLP's publications provided one means of promoting new technologies. Through this and other methods, large and small chemical suppliers provided replacement materials for what had once been a \$250 - 350 million market for CFC solvents,<sup>105</sup>

The industry response raises two important questions. First, if CFCs could be eliminated while providing a cost advantage, why hadn't manufacturers pursued these technologies in the absence of regulation? Secondly, if there was an economic gain to be achieved, why did manufacturers provide valuable technical information to the cooperative industry program?

Several factors contribute to the answer to the first question. First, industry representatives pointed out that many of the technologies had, in fact, been under development for many years. AT&T's investigation of a terpene solvent extracted from orange peels had been initiated several years before concerns about the ozone hole emerged. The early investigations had been initiated because the substance

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103. Kerr, Margaret and Chittick, David, "The Industry Cooperation for Ozone Layer Protection: It's Conception and Purpose," Industry Cooperative Ozone Layer Protection Information Flier

104 See for example, U.S. EPA/ICOLP, "Aqueous And Semi-Aqueous Alternatives for CFC-113 and Methyl Chloroform Cleaning of Printed Circuit Board Assemblies," June 1991 and U.S. EPA/ICOLP, "Alternatives for CFC-113 and Methyl Chloroform in Metal Cleaning," June 1991

105. In a 1989 case study of Du Pont's strategy for CFC replacement, Forest Reinhardt, quotes a Dupont manager saying, "We now see the ozone/regulatory situation as a marketing opportunity for substitutes." At the time, Du Pont was the world's leading supplier of CFCs. Reinhardt, Forest, "Du Pont Freon Products Division (A)," National Wildlife Federation, Washington, D.C., January, 1989

had been recognized as a potentially very useful, cost effective solvent.<sup>106</sup> More often, however, manufacturers suggested that the benefits associated with changing cleaning and degreasing processes were very small compared to the overall level of value added in their operations. Manufacturers had to compare the costs of development, the potential fire hazard, and the unknown health effects of some substitutes with the relatively small returns anticipated from modifying their operations. In short, using CFCs was the accepted means of dealing with cleaning and degreasing needs for the industry. Without the pressure of regulation no manufacturer was willing to take on the risk of trying innovative methods. Once pressured, manufacturers found that both the physical and the financial risks of innovating had been overstated and projects were identified which not only eliminated CFCs but provided traditionally acceptable rates of return.

The question of why manufacturers chose to cooperate initially seems more difficult. Why would those manufacturers who had solved their environmental problems be so quick to put their innovative methods into the public domain; particularly if the new methods were financially attractive? The answer is a combination of public relations, financial analysis, and core competencies.

As noted above, many programs aimed at eliminating CFCs were financially attractive; however, these savings were minor compared to the overall costs incurred in production. The companies decided that there was much more to be gained by enhancing an environmental image than from withholding the technology from competitors. This was particularly important to an industry which had its clean image bruised by its appearance on a number of Superfund sites. By the early 1990s, the ethic which had engendered participation in ICOLP was being rewarded as again, electronics was perceived to be among the most environmentally sound industries. In 1993, when Fortune magazine ranked the environmental leaders, five of the ten companies cited were computer or electronics manufacturers.<sup>107</sup>

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106. Boyhan, Water, Senior Staff Engineer, AT&T, Interview, January 14, 1994

107. Rice, Faye, "Who Scores Best on the Environment?" Fortune, July 26, 1993. The ten leaders cited in the article were: AT&T, Apple Computer, Church & Dwight, Clorox, Digital Equipment Corp., Dow Chemical, H.B. Fuller, IBM, Herman Miller, and Xerox.

Firms were further encouraged to publicize their CFC reducing innovations because any competitive advantage would surely have been short-lived. The innovations typically had more to do with new materials or equipment than with changes in electronics so the companies instituting the new technologies were reliant on suppliers. Suppliers had incentives to transfer technologies to other manufacturers limiting the advantage the initial firm could hold.

#### Printed Wiring Board Manufacturers:

Printed wiring board manufacturers also faced the need to eliminate CFCs from their operations. In many cases, the methods used by the larger computers and electronics firms could be adopted in the PWB operations. However, in the area of photolithography, PWB manufacturers had unique needs for CFCs.

The image on the printed wiring board was made by selectively removing areas of a copper laminate leaving behind thin traces of metal to provide a conductive path. Prior to etching operations the copper traces were isolated using a polymer layer called a photoresist. This material first had to be “developed” through a photolithography process in which unexposed regions of the material were removed (yielding a protective image which would become the copper trace). After the etching process, the protective layer of photoresist was removed in a stripping process.

In 1992, the U.S. market for dry film photoresist was approximately \$123 million and U.S. manufacturers exported an additional \$55 million of product.<sup>108</sup> Imports in the U.S. accounted for less than 5% of use. Three suppliers, DuPont, Hercules, and Morton International dominated production.

Beginning in the 1960s, the DuPont company supplied a “dry film photoresist” which was a tri-layered sheet of polyethylene, a reactive photoresist, and Mylar.<sup>109</sup> The protective polyethylene and Mylar were removed as the photoresist was laminated on the surface of the copper-epoxy/glass substrate. After exposure to light, the material was developed using methylchloroform; and after etching it was stripped

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108 USITC, Dry Film Photoresist From Japan: Determination of the Commission in investigation No. 731-TA-622 (Final), USITC publication 2630, April 1993.

109 The description of this process and further information on developments of solvent and aqueous soluble photoresists were provided by John Lott, Senior Technical Consultant, DuPont Electronics

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using methylene chloride. Water rinses removed the solvent from the surface of the board. DuPont had further provided means of removing the solvent from the water and of recycling the methylchloroform in the developing process.

Because of water discharge requirements, many manufacturers began to demand a system which would minimize chlorinated solvents in their wastewater. DuPont and other dry film manufacturers responded in the mid-1970s by introducing dry film photoresists which could be developed and stripped using aqueous materials (sodium bicarbonate or high boiling glycol ethers). Thus, when the 1990 Clean Air Act requirements demanded elimination of CFCs, those manufacturers who had not previously switched to an aqueous soluble system had a ready alternative. The costs for both the PWB manufacturers and the photoresist supplier were roughly comparable for aqueous and solvent soluble systems. Further, because of the long period over which the market moved from solvent to aqueous systems (allowing all photoresist suppliers to develop comparable products), there was little effect on the relative position of the three primary suppliers.

PWB manufacturers were also faced with a need to control releases of toxics (primarily metals) in their wastewater. As has been noted, the cost associated with these controls ranged dramatically among producers with a trend toward higher costs for smaller manufacturers. In fact, in the late 1980s, a number of programs were initiated to provide information on how PWB manufactures could reduce metals releases.<sup>110</sup> The reports offer a variety of suggestions, most of which could be categorized as follows:

- \* Water use reduction
- \* Modification of drag-out procedures (reducing the waste carried on the boards from one process to the next)
- \* Segregation of waste streams
- \* Increased metals recovery
- \* Innovative treatment chemicals

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110. See for example U.S. EPA, "Guides to Pollution Prevention: The Printed Circuit Board Manufacturing Industry," June 1990; California Department of Health Services Toxics Substances Control Program, "Waste Audit Study of the Printed Circuit Board Manufacturing Industry," June 1987; and Minnesota Technical Assistance Program, "Metal Recovery: Etchant Substitution, September, 1988

Typically, the reports offered case studies which demonstrated the potential savings which could be achieved by adopting innovative waste treatment methods. In addition, commercial organizations such as Training and Technology Inc. (TNT Inc.) began providing assistance in PWB wastewater reduction as part of their businesses.

The opportunities to reduce costs while improving environmental performance were confirmed at a variety of sites (see attached table).

Additionally, PWB manufacturers were discovering that efforts to understand their waste products provided insights which led to cost reductions outside of the waste treatment area. In a study of 33 process innovations in ten PW companies, Andrew King found that 13 were initiated by pollution control managers; cost reductions resulted in 12 of these. In the two firms which had attempted to track the value of innovations from the pollution control department, it was estimated that savings in materials costs were 2% of sales.<sup>111</sup>

Cost Saving Pollution Prevention Programs  
For Printed Wiring Board Manufacturing

Source	Project	Capital Investment	Annual Return	Payback Period
U.S. EPA	Change in wastewater treatment chemicals	Negligible	~ \$150,000	
TNT Inc.	Implementation of water reuse system		\$50,000 - \$100,000	Less than 11 months
Minnesota Technical Assistance Program	Substitution of hydrogen peroxide/sulfuric acid etchant for sodium persulfate	\$11,000	\$14,880	
California Department of Health Services	Installation of ion exchange system to reduce sludge generation	\$16,000	\$4,800	
California Department of Health Services	Installation of airspargers and flow restrictors for water use reduction	\$1,000	\$480	
Digital Equipment Corp.	Installation of ion exchange treatment system	\$1,200,000	\$490,000	

The Rio Grande Technology Foundation further demonstrated the possibilities for improving financial performance while reducing the impact of PW manufacturing on the environment. In "Project Ecocircuit," a public/private alliance (with participation of the Los Alamos National Laboratory, the New Mexico Economic Development Department, New Mexico State University, QUATRO Corp., Honeywell Incorporated, Digital Equipment Corporation, and Micrographics Corporation) set out to design an

<sup>111</sup> King, Andrew, "Innovation From Differentiation: Pollution Control Departments and Innovation in the Printed Circuit Industry," IEEE Transactions in Engineering Management, forthcoming

advanced PWB manufacturing facility which minimized the effect on the environment and improved operating performance over existing facilities. Using existing technologies, the team designed a facility which could achieve annual revenue of \$8-11 million with a reduction in waste management costs from the 2-11% reported for existing facilities to a level of 0.5 %. The revenue per employee was projected to increase from existing levels of \$62,000-\$93,000 to \$174,000-\$240,000 (a 160% increase) and the cost for a typical multilayer board was projected to be lowered from \$65-75 to \$50-60. In 1994, the team was soliciting participation in a demonstration project where they anticipated the capital costs of building a prototype facility to be \$7.2 million.<sup>112</sup>

The vast amounts of material providing a variety of waste (and cost) reduction opportunities provides an explanation for the range in environmental compliance costs. In short, manufacturing PWBs was a complex process utilizing a wide variety of potentially toxic materials. Responsibly using and controlling those materials was similarly a complex undertaking. Large firms with the (internal or contracted) resources to sift through the large amounts of data could, in fact, bring down their compliance costs. Smaller firms, unable to explore all waste reduction options, and lacking the capital to implement many of them found their environmentally driven operating costs rising with increased regulation.

The structure of the PWB industry at the time of regulation was more important to the resulting competitive effects than the regulations themselves. As has been noted, Japanese regulations were similar in stringency to those in the U.S. Using copper as an indicator, regulations in Southeast Asia are said to have been somewhat less strict but still in the 5 - 10 ppm range which required similar costs to address as the 3 ppm requirements in the U.S. and Japan.<sup>113</sup> In fact, it seems unlikely, that if U.S. regulations could be addressed for as little as 1% of sales that regulation would be a more compelling reason for industry to migrate than the labor costs advantages (labor costs were more than 20% of expense for most PWB manufacturers).

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112. "Project ECOCIRCUIT: A Clean Printed Wiring Board Factory Design," Rio Grande Technology Foundation, Albuquerque, NM, January 1994

13 Friedrichkeit, Hans J., "Germany's PCB Industry: On the Brink of Disaster?" PC FAB, September, 1992

Industry representatives often pointed to environmental costs as a driving factor in the U.S. drop in share of world production of PWBs from 40.2% in 1980 to 29.2% in 1992. Similarly, environmental costs played a role in the consolidation of the industry from 2000 firms to 900 in roughly the same period.<sup>114</sup> If, however, U.S. regulations were similar to those in the countries which gained share, why didn't similar patterns emerged in those countries? The answer seems to lie in the structural ability of firms to achieve low cost compliance. Larger firms, whether in the U.S., Japan, or Southeast Asia, benefited from the difficulty smaller firms encountered in responding to regulation. Only in the U.S. were small firms an important part of the industry as Japanese producers were supported by integrated operations and Southeast Asian production typically represented transplantation of operations from large manufacturers.

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114. Custer, Walter, "An Overview of the PCB Market," Circuits Assembly, September, 1993

## CONCLUSIONS

From its inception, the computer and electronics industry enjoyed a reputation of being among the most environmentally sound sources of knowledge-driven, high-paying jobs. The U.S. industry was stung in the mid-1980s as Superfund investigations revealed a legacy of a young industry which had depended on a variety of metals, solvents, and poisonous gases to fuel its rapid growth. The need to respond to past disposal actions was combined with increasing concern about existing operations forcing the industry to critically examine the effect its production had on the surrounding environment.

The experiences of the industry suggest the importance of industry structure in determining the competitive effects of environmental regulation. Large firms which have both the resources to investigate innovative means of compliance and the access to capital to implement those methods are in a better position to respond to regulation than small enterprises constrained by limited availability of technical personnel and restricted sources of investment funds.

In the case of the development of energy efficient computers, technology existed and was quickly incorporated into commercial products. Once the benefits of providing this technology were recognized and encouraged through the signaling of government purchasing intentions, all of the leading firms (in fact, almost all of the industry) responded. There was little competitive advantage to any one firm since their innovations were either led or quickly matched by competitors.

In the case of CFC reductions, the costs associated with eliminating the substances from production were minor compared to the overall operations of the leading firms. In fact, these firms found greater benefits from enhancing their image through cooperatively responding to the environmental challenge than from protecting their own innovative means of eliminating CFCs. Because of this cooperative response, and because most firms in these industries were large enough to assimilate the information provided by the leading firms, little competitive advantage was gained by any one firm.<sup>115</sup>

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115. Suppliers did find new markets for innovative materials. In some cases, as in the substitution of aqueous and aliphatic cleaners, new markets were gained at the expense of the previously used materials (CFCs). In others, such as dry film resist suppliers incorporated modifications in their products which were required to maintain competitive

The effects on the printed wiring board industry was very different than those associated with the production of computers or semiconductors. Where the later two industries had important economies of scale and large barriers to entry, the U.S. PWB industry provided few barriers to entry and had traditionally provided limited scale economies. As a result, this industry was much more fragmented when environmental concerns became an important part of their operations. Despite concerted efforts by industry and regulatory groups, the smaller firms were experiencing disproportionately high pollution abatement and control costs in the early 1990s. Additionally, environmental costs were frequently cited as a contributing factor to the U.S. loss of world share in PWB manufacturing. However, controls in countries gaining share were as rigorous as those in the U.S. The evidence suggests that it was not the regulations themselves, but the regulations coupled with the fragmentary industry structure which made environmental issues a factor in the declining U.S. market.<sup>116</sup> Small U.S. firms simply could not assimilate the vast amounts of information needed to respond to environmental regulations in a cost effective manner. Finding themselves in a higher cost position, these firms lost market share to their larger competitors, whether they be domestic or foreign.

The experiences of the U.S. electronics manufacturers should not be considered unique. In any industry where environmental regulations are uniformly applied, technology is readily available, and firms have roughly similar investment resources, the regulations are unlikely to yield competitive advantage to any one company (or the companies of any one nation). However, even with similar regulations, firms with unique technologies or with greater resources to investigate and implement more cost effective technologies can benefit from those regulations. Further, if the industry structure differs from one nation to another, environmental regulations can contribute to changes in international trade and movement in shares of international markets.

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position.

16. Pollution abatement and control is hardly the only (or perhaps even a leading) factor in the decline of the U.S. position. Other contributing factors included differential wage rates, exchange rate changes, and movement of the buying industries (computer and electronic manufacturing) to non-U.S. locations. This discussion merely points out how environmental controls can be a factor in competitiveness when the regulations themselves appear very similar.

Table 1  
World Manufacturing of Computers and Components  
Share of World Production  
(by firm headquarters location)

	Computer Hardware <sup>1</sup>	Semiconductors <sup>2</sup>	Printed wiring Boards <sup>3</sup>	Semiconductor Equipment <sup>4</sup>
Year	1992	1992	1992	1990
United States	61%	42.6%	29%	45% <sup>5</sup>
Japan	30%	43.4%	30%	44% <sup>5</sup>
Europe	8%		16%	
Other	1%	14.9%	25%	9%
		(inc. Europe)		(inc. Europe)

<sup>1</sup>Source: U.S. ITC, "Global Competitiveness of U.S. Advanced-Technology Industries: Computers"

<sup>2</sup>Source: Semiconductor Industry Association, "Status Report and Industry Directory: 1994-1995"

<sup>3</sup>Source: The Institute for Interconnecting and Packaging Electronic Circuits, "TRMC: Report on the World Market for Printed Wiring Boards and Substrate Materials for 1992"

<sup>4</sup>Source: U.S. ITC, "Global Competitiveness of U.S. Advanced-Technology Manufacturing Industries: Semiconductor Manufacturing and Testing Equipment"

<sup>5</sup>3% of sales are by U.S.-Japan Joint Ventures

Table 2  
1992 End Use Markets for Electronic Components

Market Segment	Semiconductor Share of World Market <sup>1</sup>	Merchant Primed Wiring Boards Share of U.S. Market <sup>2</sup>
Computer	43%	45.0%
Consumer Electronics	25%	4.2%
Telecommunications	13%	16.4%
Industrial/Instruments	11%	15.7%
Automotive	5.5%	10.4%
Military/Government	3%	8.3%

<sup>1</sup>Source: U.S. ITC, "Industry and Trade Summary: Semiconductors"

<sup>2</sup>Source: The Institute for Interconnecting and Packaging Electronic Circuits, "TMRC Analysis of the Market: Rigid Printed Wiring Boards and Related Materials for the Year 1992"

The Computer and Electronic Component Industry

Table 3  
Computer Hardware Manufacturers  
personal Computers 1992 Revenue

Company	Headquarters Country	Revenue (\$ Million)
IBM	U.S.	\$5,941
NEC	Japan	\$5,849
Apple	U.S.	\$5,599
Compaq	U.S.	\$3,784
Fujitsu	Japan	\$2,330
Matsushita	Japan	\$2,209
Dell	U.S.	\$1,752
Toshiba	Japan	\$1,558

Total Market \$46 Billion

Source: U.S. ITC Global Competitiveness of U.S. Advanced Technology Industries: Computers

Table 4  
Computer Hardware Manufacturers  
Workstations 1991 Revenue

Company	Headquarters Country	Revenue (\$ million)
Sun Microsystems	U.S.	\$3,112
Hewlett Packard	U.S.	\$1,712
IBM	U.S.	\$937
DEC	U.S.	\$937
Silicon Graphics	U.S.	\$814
Intergraph	U.S.	\$568
Total Market		\$10 Billion

Source: U.S. ITC Global Competitiveness of U.S. Advanced Technology Industries: Computers

Table 5  
Computer Hardware Manufacturers  
Mainframes & Minicomputers 1992 Revenue

Company	Headquarters Country	Revenue (\$ million)
IBM	U.S.	\$20,823
Fujitsu	Japan	\$8,036
Hewlett-Packard	U.S.	\$4,496
Hitachi	Japan	\$4,418
DEC	U.S.	\$3,413
NEC	Japan	\$3,026
Unisys	U.S.	\$2,442
Siemens	Germany	\$2,075
Total Market		\$56 Billion

Source: U.S. ITC, Global Competitiveness of U.S. Advanced Technology Industries: Computers\*

Table 6  
Computer Hardware Manufacturers  
Supercomputers 1992 Revenue

Company	Headquarters Country	Revenue (\$ million)
Cray Research	U.S.	\$649
IBM	U.S.	\$263
Fujitsu	Japan	\$261
Convex	U.S.	\$163
NEC	Japan	\$134
Intel	U.S.	\$94
Thinking Machines	U.S.	\$88
Hitachi	Japan	\$49
Total Market		\$2 Billion

Source: U.S. ITC, Global Competitiveness of U.S. Advanced Technology Industries: Computers\*

Table 7  
Computers and Central Processing Units  
Share of World Exports

Country	1980	1985	1990
United States	45%	33%	30%
United Kingdom	10%	9%	16%
Japan	5%	10%	10%
Germany	18%	11%	9%
Ireland	5%	12%	9%
France	5%	6%	5%
Singapore	0%	1%	3%
Netherlands	2%	3%	3%

Source: UN Trade Statistic Yearbook

Table 8  
Computers and Central Processing units  
Share of World Imports

Country	1980	1985	1990
United States	NA	NA	9%
United Kingdom	13%	15%	11%
Japan	8%	7%	6%
Germany	18%	15%	14%
Ireland	2%	1%	1%
France	9%	11%	12%
Singapore	1%	1%	2%
Netherlands	7%	7%	6%

Source: UN Trade Statistic Yearbook

Table 9  
computers and Central Processing units  
Balance of Trade  
(million dollars)

Country	1980	1985	1990
United States	n.a.	n.a.	\$5,078
United Kingdom	(\$95)	(\$422)	\$1,068
Japan	(\$129)	\$324	\$1,026
Germany	\$75	(\$345)	(\$1,760)
Ireland	\$152	\$1,058	\$2,116
France	(\$136)	(\$495)	(\$1,759)
Singapore	(\$23)	(\$27)	\$353
Netherlands	(\$191)	(\$286)	(\$785)

Source: UN Trade Statistics Yearbook

Table 10  
Microcircuits (Semiconductors)  
Share of World Exports

Country	1990	1985	1980
United States	26.7%	13.9%	17.0%
Japan	17.9%	20.0%	13.4%
Republic of Korea	9.5%	6.3%	5.6%
Singapore	6.6%	7.8%	11.8%
Malaysia	6.4%	12.5%	n.a.
Germany	6.4%	5.9%	7.9%
United Kingdom	5.3%	7.4%	4.4%
Hong Kong	4.0%	4.3%	3.7%
France	3.7%	3.6%	2.3%
Italy	2.1%	2.1%	1.3%

Source: UN Trade Statistic Yearbook

Table 11  
Microcircuits (Semiconductors)  
Share of World Imports

Country	1990	1985	1980
United States	26.6%	34.6%	40.4%
Japan	6.5%	5.5%	7.0%
Republic of Korea	6.9%	2.1%	1.2%
Singapore	7.6%	6.1%	4.0%
Malaysia	3.6%	2.1%	n.a.
Germany	7.4%	10.4%	13.4%
United Kingdom	7.0%	9.2%	6.1%
Hong Kong	6.8%	5.9%	4.9%
France	4.9%	5.0%	6.1%
Italy	5.9%	4.7%	3.9%

Source: UN Trade Statistic Yearbook

Table 12  
Microcircuits (Semiconductors)  
Balance of Trade  
(million dollars)

Country	1990	1985	1980
United States	\$807	(\$2,743)	(\$1,786)
Japan	\$5,078	\$1,716	\$320
Republic of Korea	\$1,314	\$499	\$259
Singapore	(\$214)	\$161	\$434
Malaysia	\$1,330	\$1,245	n.a.
Germany	(\$224)	(\$603)	(\$452)
United Kingdom	(\$510)	(\$274)	(\$159)
Hong Kong	(\$1,001)	(\$232)	(\$116)
France	(\$387)	(\$201)	(\$287)
Italy	(\$1,461)	(\$334)	(\$190)

Source: UN Trade Statistic Yearbook

**Table 13**  
**Chemical Releases by U.S. Electrical Device and**  
**Electronic Component Manufacturers**

Chemical	Pounds Released	Share of Industry Releases	Total Releases of TRI Reporting Industries	Electrical Device and Component Share of Total
1,1,1 Trichloroethane	20,946,321	14.37%	185,026,191	11.32%
Freon 113	19,287,519	13.23%	67,837,298	28.43%
Xylene	15,161,270	10.4%	185,442,035	8.18%
Dichloromethane	9,170,339	6.29%	130,355,581	7.04%
Sulfuric Acid	8,640,177	5.93%	318,395,014	2.71%
Acetone	8,513,166	5.84%	255,502,000	3.33%
Toluene	5,943,189	4.06%	322,521,176	1.84%
Trichloroethylene	5,516,372	3.78%	48,976,806	11.26%
Glycol Ethers	5,047,653	3.46%		
Ammonium Sulfate	4,879,304	3.35%	750,649,064	0.65%
		<b>70.74%</b>		

Source: U.S. EPA Toxics Release Inventory

The Computer and Electronic Component Industry

Table 14  
Pollution Abatement Capital Expenditures  
By U.S. Electrical Device and Electronic Component Manufacturers

	1991 Total Capital Expenditures (million)	1991 Environmental Capital Expenditures (million)	Share of Total Expenditures
Printed Circuit Boards	\$311.1	\$17.5	5.6%
Semiconductors	\$2,945.0	\$106.2	3.6%
Communications Equipment	\$1,114.4	\$5.4	0.5%
Computer and Office Equipment	\$1,938.6	\$16.6	0.9%

Source: U.S. Department of Commerce, "Annual Survey of Manufacturers," and "Current Industrial Reports: Pollution Abatement Costs and Expenditures"

Table 15  
Pollution Abatement Operating Costs  
By U.S. Electrical Device and Electronic Component Manufacturers

	1991 Value of Industry Shipments (million)	1991 Environmental Operating Costs (million)	Share of Total Shipments
Printed Circuit Boards	\$6,352.9	\$81.3	1.3%
Semiconductors	\$29,668.1	\$116.4	0.4%
Communications Equipment	\$37,945.9	\$45.8	0.1%
Computer and Office Equipment	\$27,418.5	\$71.3	0.1%

Source: U.S. Department of Commerce, "Annual Survey of Manufacturers," and "Current Industrial Reports: Pollution Abatement Costs and Expenditures"